ESTIMATING ANCESTRAL ORIGIN OF HUMAN SKULLS WITH MAXILLARY AND MANDIBULAR MORPHOMETRICS

By

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A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

1996

This work is lovingly dedicated to my father William Howard Austin (November 19, 1938 - April 16, 1990). He taught me to live my dream.

ACKNOWLEDGMENTS

The completion of a dissertation is but one part of the process in achieving the Ph.D. Along the road, many individuals teach and encourage the doctoral student. I am deeply indebted to Dr. William Maples who began the mentoring process with me many years ago. He shared his extensive knowledge of forensic anthropology in a manner that fostered confidence and competence. He made time to answer my many questions about the field and about life. He's been an exceptional mentor and a superb role model.

I am grateful to Dr. Leslie Lieberman for her guidance throughout my research. She has been a valuable source of information and consistent encouragement and caring. I wish to thank Dr. Susan Anton for her careful review of my dissertation. Her suggestions have greatly improved my work. Dr. William Hamilton has been an outstanding teacher of forensic pathology through the years. Although our interactions were never in a classroom setting, he took every opportunity to turn a forensic case into a learning experience for all involved. I am also indebted to Dr. Ronald Baughman for his help in securing the dental model sample used in this research and for his suggestions regarding my research project.

My research required travel to Washington D. C. and Cleveland, Ohio. Dr. Dave Hunt, collections manager at the Smithsonian Institution, provided valuable assistance with his extensive knowledge of the skeletal collections. Thanks also to Dr. Doug Ubelaker for his encouragement while I was visiting. My stay in Washington was made pleasant by the fine, fine company of my good friends who sheltered, fed, and taxied me while I was there. Many, many thanks to Terry Fisher, Mark Gormley, Alison Green, Joe Trahan, the folks at Tunnicliffs, Rich Austin, and Arneta Austin.

At the Cleveland Museum of Natural History I was capably assisted by Lyman Jellema. Mr. Jellema took the time to show me the collections and many of the treasures of his museum. Dr. Bruce Latimer was also encouraging and helpful.

I wish to thank the department of orthodontics at the University of Florida College of Dentistry for allowing me to use their dental model collection. Dr. Timothy Wheeler, Deb Brown, and Karen Owens created space for me to work and were always helpful.

Dr. Susan Stans has been a great source of encouragement and company to me throughout the entire doctoral process. She mentored me as a teaching assistant and shared a great deal with me as we both completed our research and writing. Although she finished before me, it was always a friendly competition that I believe helped both of us reach our goals.

Many other friends have helped me keep the faith. Ruth Trocolli, Michael Fitzgerald, Karen Owens, Andrea Dudash, Lisa Hoshower, Lenore Barbian, Steve Mizrach, Anne Stokes, Tom Abel, Rob Patton, Linda Stern, and Michael McGuiness were each supportive and provided me with helpful suggestions and much fun along the way. Beth McCann, Bunny Ingles, and Cheryl Katzmarzyk deserve special mention for allowing me to stay with them on many occasions when I was commuting between Jacksonville and Gainesville. My new friends in Fort Worth, Gary Sisler, Beni Brown, and Ronnie Redic, have also provided much encouragement and good company.

In addition to a comfortable bed and dinner on the table whenever I needed it, Beth McCann loaned me her computer when mine died and offered countless hours of technical and emotional support. I would have been lost without her.

Many thanks to my sister, Sherry Austin Fore, who continually told me I can do it. A special thank you is owed to my husband Jim Smith. He supported me during the entire process and did not pressure me to finish. Words can not express my gratitude for his faith in me and his ability to make me laugh.

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Abstract of Dissertation Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Doctor of Philosophy

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By

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December, 1996

Chairman: William R. Maples, Ph.D.
Major Department: Anthropology

Predicting the race of an unknown skull is useful in making a personal identification. Discriminant function techniques are used; however, none have attempted to describe the differences seen in the arcade shape of the jaws. This study metrically evaluated the range of arcade shape variability within and between three racial groups.

The data consisted of inter-tooth distances, width, and length of upper and lower arcades. The measurements were collected on skulls and dental models of known sex, race and adult age. One hundred and one female and 100 male African American, 86 female and 100 male European Americans, and 55 female and 118 male Asian skulls were evaluated. Dental models of 27 female and 21 male African Americans and 103 female and 100 male European Americans were analyzed for secular trend changes in populations from the early part of this century.

ANOVA, the Tukey post hoc test ($p<0.05$), and MANOVA resulted in significantly different racial group means for most of the measurements. Discriminant analysis results were varied. Maxillary measurements were more reliable in the Asian sample (67% to 70%) than the African American sample (50%) and the European American sample (43% to 57%). mandibular measurements were reliable in the African American sample (76%) and ver poor in the other two (35% to 47%). The dental model sample reliability was excellent in the European American sample (96% to 98%) and poor in the African American sample (22% to 31%).

The relative inter-tooth distances from canine to second molar reflect a change in shape of the tooth row from anterior to posterior. Orthogonal polynomial contrast detected linear and quadratic trends. The patterns in the three racial groups were significantly different from one another in the maxilla and supported previously reported nonmetric shape characteristics. Mandibular maximum distance patterns were significantly different for the African American sample only.

Analysis of secular trend changes indicated a decrease in inter-tooth distances anteriorly and an increase in width over time in the posterior teeth.

CHAPTER 1
INTRODUCTION TO THE PROBLEM, BACKGROUND AND LITERATURE REVIEW

Introduction

The race of an individual is a crucial part of the biological profile generated by the forensic anthropologist and used by death investigators in American culture. Forensic identification of skeletal remains describes and quantifies geographical variation in anatomical structures to identify ancestral affiliation. Metric analyses of cranial features has proven useful in assessing the ancestral stock of unidentified human skulls (Giles and Elliot, 1962; Howells, 1978; Johnson et al., 1989). Length, breadth, and height of the cranium as well as several other cranial measurements discriminated between racial groups with 70 to 95 percent accuracy (Giles and Elliot, 1962; Howells, 1978; Johnson et al., 1989).

Although the shape of the palatal arcade is a useful nonmetric indicator of race (Krogman, 1949; Kerley, 1973), the scope of inter- and intraracial variability has yet to be fully examined (Gill, 1986; Gill and Chapman, n.d.).

Likewise, differences in palatal and mandibular arcade shape have never been studied metrically on large racially distinct populations. This research explores the range of variability in the shape of the maxillary and mandibular arcades and determines the usefulness of arcade shape in the assessment of race of unidentified human jaws.

I used skeletal material of known race to quantify morphological differences between groups. I introduced new measurements that partially describe upper and lower dental arcade shape: measurements between paired bilateral teeth from canine to second molar. I evaluated ancestral group variation in the jaws of modern humans inter- and intraracially. The measurements in this study were selected to reflect group differences such that unknown material could be assigned racial group with a high degree of accuracy.

This research further assessed how well data collected from the Terry and Hamann-Todd collections reflects that of more recent individuals. Secular trends, environmentally induced changes in morphology from one generation to another, have affected the usefulness of forensic identification techniques (Henneberg and George, 1995; Ayers et al., 1990). Techniques developed on a population from an earlier time period are not always as accurate when utilized on a more recent population (Ayers et al., 1990). Individuals in the Terry and Hammann-Todd collections lived during the early part of this century and thus are not truly contemporary with modern Americans. These two skeletal collections are the most frequently used by forensic anthropology researchers and made up the bulk of the data in this research project. To test their suitability they were compared with a true contemporary population from the 1970s to 1990s to ascertain secular trend changes in the arcade shape over the past 50 years.

Variation of the Human Skull: Causes of Variation and Uses for Racial Identification

The following literature review documents the biological mechanisms responsible for idiosyncratic and geographic variation. Modeling and remodeling of bone and pre- and postnatal growth and development of the jaw structures are reviewed. Variation in human dental arches with regard to sex and race and metric and nonmetric methods that determined race from the dental arches, skull, cranium, and/or mandible are discussed.

Influences of Bone Shape and Size

Modeling and Remodeling

Changes in the gross morphology of bone through an individual's life are determined by the cellular processes of modeling and remodeling (Petrovic et al., 1975; Frost, 1976).

Bone maintains a semi-permanent record of the location, intensity, and nature of its cells' functions. Osteoclastic and osteoblastic activity result in bone resorption and formation respectively. Osteoclasts secrete acid, collagenase, and other proteolytic enzymes that attack bone matrix and liberate calcified ground substance (Junquiera et al., 1986). Osteoblasts, found at the periosteal and endosteal surfaces of bone, secrete unmineralized bone matrix (osteoid). An osteoblast secretes matrix until it is completely surrounded and is referred to as an osteocyte (Junquiera et al., 1986).

Modeling modifies and controls the architecture of the growing skeleton on the periosteal and endosteal surfaces (Frost, 1966). Bone tissue arises either intramembrously, within a layer of condensed mesenchyme, or endochondrally, within a cartilaginous model. The first bone tissue to appear is immature or primary bone (also termed woven bone). This is a temporary tissue that is soon replaced by secondary bone with a lamellar structure (Junquiera et al., 1986).

Remodeling occurs throughout life on all surfaces of the bone, (i.e. periosteal, endosteal, and Haversian system) (Frost, 1966). The cellular units of remodeling, lamellar basic multicellular units (BMUs), have directionality in three-dimensional space in response to biomechanical factors and create the grain of the bone (Frost, 1966). Remodeling begins with the removal of bone by multi-nucleated, mobile osteoclast cells that resorb bone in approximately 60 days

(+/- 70%) (Frost, 1966). The resorption space is filled with new osteoid laid by immobile, mononucleated osteoblast cells. The osteoid or bone matrix is composed of type I collagen, proteoglycans, and glycoproteins (Junquiera et al., 1986). The osteoid is infused with inorganic molecules of calcium, phosphorus, and small amounts of bicarbonate, citrate, magnesium, potassium and sodium to make hard bone in approximately 80 days (+/- 20%) (Frost, 1966; Ortner and Putschar, 1985; Junquiera et al., 1986). The entire resorption/deposition process takes 3 to 4 months in humans and slows with age (Frost, 1976; Behrents, 1985).

Strain, caused by muscular activity at the periosteal border, stimulates remodeling (Harvold, 1975b; Schumacher, 1985). Periodontal, dental, articular, and mucosal ligaments, and complimentary and opposing muscle groups determine the shape of the jaw bones through strain-induced remodeling (Petrovic et al., 1975). At 1500-3000 microstrain cortical bone mass increases. Normal lamellar bone fractures at 25,000 microstrain. Microstrain levels of 100-300 and below lead to removal of cortical-endosteal and trabecular bone via remodeling (Frost, 1987). Feedback mechanisms at the cellular and macroscopic levels indicate an hierarchical mode of gene regulation in cell turnover activity (Hunter, 1990). Muscular activity is controlled by a separate genetic component and is an epigenetic factor for bone remodeling (Hunter, 1990).

Growth Regulation

During fetal and postnatal growth and development tissues with functional physiological priority begin growth earlier or grow proportionately faster than other tissues (Enlow, 1990). In fetal life, the cardiovascular and nervous systems have more functional demands than lungs, nasal, and oral structures and thus are most influential in the development of the fetus (Enlow, 1990). A relatively larger brain, calvaria, basicranium, and eyes with a smaller face at birth results. At birth, the face is vertically short, compared to the adult, due to the underdeveloped nasal cavities and maxillary sinuses and the undeveloped alveolar regions (Trotter and Peterson, 1966). During postnatal growth, lung size, airway size, dentition development, and masticatory complex development lead to differential growth of the facial area (Enlow, 1990; Kean and Houghton, 1990). Growth in these areas is rapid in the first seven years and again at puberty. At puberty, the air sinuses enlarge, changing the size and form of the face (Trotter and Peterson, 1966).

In early childhood the most significant development in the midface is an increase in height. Width is limited by placement of the orbits, the cranial sutures of the nasomaxillary complex, and the positions of the glenoid fossae on the basicranium (Enlow, 1990; Kean and Houghton, 1990). Height is increased by lowering the floor of the nose, the bony palate, and the maxillary occlusal plane (Kean and Houghton, 1990).

The maxillary dental arch acts as the reference point for differential growth and dependency systems in the jaws. Occlusal maintenance causes continued remodeling in the jaws (Petrovic, 1975). The mandible grows and moves in relation to the upper jaw. Experimentally produced variations in the elongation of the maxilla stimulate condylar growth in the same direction and amount (Petrovic, 1975). Normally, the upper arch is displaced anteroposteriorly during growth (Enlow, 1990) and the lower arch follows (Petrovic, 1975).

Growth mechanisms of the mandible are governed by two processes. The first, an overall regulation by somatotrophic hormone, affects primary cartilage such as the synchondroses of the cranial base and the nasal septum. Hormonal regulation also affects the periosteal contributions (Petrovic et al., 1975). Secondly, local feedback systems, found throughout the mandible, regulate secondary cartilage structures. Periodontal, dental, articular, mucosal, and muscular site receptors signal deviation from occlusion. Growth at the secondary cartilages, condylar and coronoid, is responsible for fine adjustments ensuring efficient occlusion (Petrovic et al., 1975).

Development and Growth

The cranium has cartilaginous bones on the sides and base and membranous bones on the top and sides (Trotter and Peterson, 1966). During the fourth week in utero the basicranium or chondrocranium becomes organized developing concomitantly with the brain and cranial nerves (Gray, 1974; Ranly, 1980). At this stage, the cartilages are designated as parachordal and prechordal in reference to their relationship to the notochord (Ranly, 1980). Cartilage precursors of cranial base bones appear by the seventh week (Ranly, 1980). The basal plate is formed in the midline from fused parachordal and occipital sclerotomic condensations. Laterally, the otic capsules are formed and become the petromastoid areas of the temporal bone. Anterior to the basal plate, polar cartilages unite medially to form part of the sphenoid. The body of the sphenoid (trabecular cartilage) is formed from prechordal condensations which extend rostrally to the nasal capsule. Bilaterally to the midline, the orbitosphenoids (greater wing) are formed in cartilage and the alisphenoids (lesser wing) in cartilage and membranous bone (Ranly, 1980). The nasal capsule is most anterior and develops into the ethmoid, nasal conchae, and nasal septum (Ranly, 1980).

Calvarial development begins with brain vesicles wrapped in a mesenchymal capsule, termed the membranous cranium (Trotter and Peterson, 1966). The parietals, frontals, squamous portions of the temporals, and occipital are intramembranous in origin (Ranly, 1980). Membranous ossification commences in the sixth and seventh weeks in utero and continues through puberty (Ranly, 1980).

The ethmoidal region of the basicranium forms a platform that suspends the upper facial skeleton. At four weeks in utero the mouth begins as a depression called the stomodeum (Patton, 1968). Facial growth occurs anterior to the stomodeum largely from intramembranous ossification of portions of the embryonic pharyngeal arches. Initially the pharyngeal arches are separated from the stomodeum by the buccopharyngeal membrane which breaks down as rapid development takes place (Patton, 1968).

The maxillary and mandibular origins are evident as swellings of the first pharyngeal arch at about five weeks (Patton, 1968; Ranly, 1980). The first centers of intramembranous ossification of the maxilla form above the canine tooth germ at the end of the sixth week in utero (Woo, 1949). At seven weeks the maxillary swelling and the medial nasal swellings fuse to form the maxillary arch. The medial nasal swellings form the premaxilla and the philtrum. The lateral portion of the nasal swellings become the nasal wings (Patton, 1968). The palatal shelves of the maxillae extend toward the midline forming the hard palate and separating the oral and nasal cavities (Patton, 1968). Successful palatal closure occurs only if the tongue descends. The growth of Meckel's cartilage thus removes the tongue from between the palatal shelves. Failure of such growth results in posterior cleft palate (Ranly, 1980; Enlow, 1990).

Growth of the palate is more rapid in length than in width for the first trimester in utero. The reverse is true during the final two trimesters (Kraus and Decker, 1960). It has been suggested that decreased transverse growth aids in fusion of the palatal shelves and that groups with broad palates have relatively greater frequency of cleft palate (Ranly, 1980).

During the first trimester, the nasal chamber expands laterally and inferiorly displacing the palatal shelves inferiorly (Enlow, 1990). The nasal septum extends inferiorly until it joins with the superior surface of the palate (Enlow, 1990). In the young child the lateral nasal walls rapidly expand outward (Mauser et al., 1975). The nasal side of the palate is resorptive and the oral palate is depository causing inferior movement of the palate and a height increase of the nasal cavity (Mauser et al., 1975).

The mechanism for the inferior/anterior displacement of the palate is debated. One hypothesis suggests that the nasal septum pulls the premaxilla with it as it grows forward and downward (Latham, 1976). A competing theory, the functional matrix concept, surmises movement and growth of bones and cartilage due to the function of all the soft tissues acting in association with the bone (Moss and Selantinjin, 1969).

The cartilage of the first pharyngeal arch, Meckel's cartilage, develops into the core of the mandibular corpus (Patton, 1968). The bony mandible develops by intramembranous ossification lateral to Meckel's cartilages. Anteriorly, the two halves remain separate at the symphysis until shortly after birth (Ranly, 1980).

The convexity of the inferior surface of the mandibular body is directly related to the stress placed by the masseter and internal pterygoid muscles (Harvold, 1975a). Larger muscles produce a sharper curve. This system can be visualized as an arch with the keystone at the gonial angle and the two legs extending to the temperomandibular joint and the chin (Harvold, 1975a). More weight (larger muscles) leads to more bowing of the legs (Harvold, 1975a). Larger muscles lead to more space in the oral cavity (Harvold, 1975a).

In utero, partial mandibular rami without condyle or coronoid processes are present (Ranley, 1980). During childhood, both vertical enlargement of the midface and ramus and horizontal growth (breadth) of the corpus causes the ramus to remodel (Enlow, 1975). As upward and backward growth of the mandible occurs the rami are transformed into the vertically inclined adult form (Kean and Houghton, 1990). Most of the remodeling at the junction between the corpus and angle of the ramus changes the position of the ramus. The ramus is displaced posteriorly during corpus elongation as the ramus tissue is remodeled into corpus tissue. The corpus grows by bony deposition on the inferior border, not at pogonion (Bjork, 1963). The dentition remains in it's original position (Enlow, 1975).

The mandibular rami relate to the pharyngeal space and the middle cranial fossa and function to locate the corpus of the mandible in proper anatomical position (Enlow, 1975). The ramus grows horizontally in response to growth of the middle cranial fossa and vertically in response to vertical growth of the nasomaxillary complex and dental eruption (Enlow, 1975). After the pharyngeal space and the middle cranial fossa have ceased to grow, the remodeling pattern alters. The corpus is lengthened to create space for the third molar, the condyles grow anterosuperiorly, the rami are vertically enlarged without broadening (Enlow, 1975). The mandibular fossa of the cranium takes on an adult shape and deepens between six months and two and a half years of age (Wright and Moffett, 1974).

The endochondral condylar and coronoid cartilages appear around the twelfth week in-utero (Ranly, 1980). Condylar cartilage, a secondary cartilage, has the capacity to grow in many directions (Enlow, 1975; Petrovic et al., 1975). As the mandible is displaced during growth the condylar cartilage maintains the condyle's proper anatomical position (Enlow, 1975). Coronoid process and condyle growth effect the position of the chin. Excessive condylar growth leads to protraction of the chin, whereas excess growth of the coronoid process will cause a retracted chin (Ricketts, 1975).

Tooth Development and Eruption

Tooth development occurs within the alveolar bone of the jaws. By the sixth week in utero, the basal layer of the epithelial lining of the oral cavity forms the dental lamina in both jaws. The lamina gives rise to ten outbuddings per jaw which penetrate the underlying mesenchyme and form the ectodermal components of the teeth (Langman, 1963). At 10 weeks in utero, the dental primordia are present in both jaws causing resorption of the alveolar wall to accommodate the growing deciduous tooth buds (Arey, 1965). The deep surface of the bud invaginates and differentiates into the outer and inner dental epithelia, central stellate reticulum, and dental papilla. The papilla cells differentiate into odontoblasts and produce the predentine that eventually calcifies into dentin. The epithelial cells of the inner dental layer differentiate into ameloblasts. Ameloblasts produce enamel prisms that are deposited over the dentin (Langman, 1963). The point at which the outer epithelium and inner epithelium meet is termed the cervical loop (Junquiera et al., 1986).

Crown development precedes root development (Wheeler, 1940). Enamel is deposited first over the apex of the crown and spreads toward the neck (Langman, 1963). Calcification of enamel and dentin begins in the deciduous incisor and molar crowns as early as the fourth month in utero (Wheeler, 1940). Each tooth has four or more centers, called lobes, that unite at the completion of the crown.

Root development begins after the crowns are complete, shortly before eruption. The cervical loop penetrates deep to the crown to envelop the dental papilla and form the epithelial root sheath. The inner epithelial layer differentiates into odontoblasts and deposits a layer of dentin continuous with the layer of the crown. Mesenchymal cells located external to the tooth become cementoblasts (Langman, 1963; Junquiera, 1986). Cementum covers the dentin in the root area, enamel in the crown area. The junction of dentine and enamel is the cervical line, a demarcation between the cervix of the crown and the root (Wheeler, 1940). Outside of the cement layer, the periodontal ligament forms from mesenchyme. It connects the cementum to the bony wall of the alveolar socket and holds the tooth in place (Langman, 1963).

As the root continues to form, it pushes the crown occlusally causing it to erupt into the oral cavity. Root calcification is normally unfinished when the tooth erupts and continues until cementum covers all of the root surface except for the apical foramen.

The anterior surface of the incisor area in both jaws is depository in fetal life and early childhood to accommodate the deciduous dentition and the buds of the permanent teeth (Mauser et al., 1975; Kurihara and Enlow, 1980).

Deciduous eruption begins between 7 to 8 postnatal months and is completed by two and a half years (Arey, 1965). The depository nature of the anterior surface of the incisor area ceases at about six years, after all the tooth buds have been formed and the deciduous teeth have erupted (Mauser et al., 1975).

The deciduous teeth are in use between five and eleven and a half years and contribute to normal jaw development through use (Wheeler, 1940). Premature loss of deciduous teeth can lead to abnormal development of the deciduous dental arch and abnormal placement of the permanent dentition (Wheeler, 1940).

The buds for the permanent dentition are located lingually to the deciduous teeth. Twenty regions, corresponding to the permanent counterpart of a deciduous tooth plus the tooth germs of the three permanent molars are identified (Junquiera et al., 1986). Although most of these buds are formed between the third fetal month and birth they remain dormant until about the sixth postnatal year (Langman, 1963; Arey, 1965). Tooth germs for the second and third permanent molars are formed postnatally (Junquiera et al., 1986). The permanent first molars begin to calcify during the first month postnatal and are the earliest permanent teeth to erupt at about six years of age. The first molars are followed by the central incisors, lateral incisors, first premolars, mandibular canines, second premolars, maxillary canines, second molars, and third molars respectively

(Wheeler, 1940). Third molar formation and eruption is highly variable and often there is agenesis in these structures (Nanda, 1954; Garn et al., 1962; Richardson, 1977; Taylor, 1978; Mincer et al., 1993).

Genetic Determinants of Facial Shape

Osteogenesis during craniofacial growth is mainly controlled by a polygenetic system that is influenced by exogenic factors (Schumacher, 1985). No Mendelian components have been clearly identified because environmental factors influence final form to such a great extent that it is difficult to detect the causal mechanism (Hunter, 1990). The number of environmental factors is tremendous and begins before conception (Shumacher, 1985). Hormone levels, sex of the individual, and nutritional status are examples.

Studies suggest that the chondrocranium is determined primarily by genetic factors (Schumacher, 1985), whereas the neurocranium is more subject to exogenic factors collectively called the functional matrix (Moss, 1962). Homeobox-containing genes encode a special group of transcription factors that regulate patterning of the head and face, particularly tooth development (Thesleff, 1995). These genes are influenced by bone morphogenetic proteins found between tissue layers in the embryo (Thesleff, 1995).

A likely independent genetic determinant of the upper and lower halves of the cranio-facial complex, maxillary height, and maxillary depth was discovered in a study of monozygotic and same sex dizygotic twins (Nakata, et. al, 1974; Nakata, 1995). Maxillary height was correlated with overall body stature and mandibular growth appeared to have both genetic and environmental factors for growth (Nakata, et. al, 1974). Cephalometric studies have shown moderate to high heritability rates for cranial and dental measurements, but lower heritabilities for measurements associated with malocclusion such as tooth position and dental interrelationships (King et al., 1993).

Depth measurements such as maxillary length, mandibular length, and overjet are more affected by environmental factors than are vertical measurements (Hunter, 1965). Ninety percent of variation in overjet, overbite, crowding, rotation, and molar relationship is environmental while only 40 percent of arch width at canines and molars and arch length is environmental (Harris and Smith, 1980). A study of six horizontal and six vertical measurements found a tendency for horizontal measurements to show more environmental influence, but the trend was not statistically significant (Lundstrom and McWilliam, 1988).

Racial Variation in the Craniofacial Complex

In order to identify a skeleton or body, race identification and other biological criteria are established. This information is compared to a list of missing persons for a possible match. The skull contains more information regarding racial variation than the postcranial skeleton (Kerley, 1973; Stewart, 1979; Krogman and Iscan, 1986). In the following literature survey craniometric and nonmetric methods for racial identification are reviewed.

Craniometrics

Racial estimation via discriminant function analysis based on cranial metrics give reliable results (Giles and Elliot, 1962; Howells, 1973; Gill, 1986; Johnson et. al, 1989). Howells (1973) compared 17 geographically and culturally defined populations through an exhaustive series of measurements and angles over the cranium. His multivariate analysis yielded a multitude of discriminant functions that distinguish groups (Howells, 1973). However, his work did not include analysis of the mandible.

In a similar study, Giles and Elliot (1962) used eight vault measurements to distinguish African, European, and Native Americans from one another. This method accurately distinguished African Americans from White Americans; however, the limited sample did not lead to clear discrimination between Western Amerindians and Whites (Gill and Gilbert, 1990; Birkby, 1966; Gill, 1995). An alternative method measuring the area inferior and lateral to nasion including the entire nasal bone, frontal process of the maxilla, and the zygoorbital points was measured using a specialized set of calipers in Amerindian, White, and Black skulls (Gill, 1986; Gill and Gilbert, 1990; Gill, 1995). Gill's method is especially useful in categorizing Western states Amerindian skulls from Whites, a distinction poorly developed in Giles and Elliot's work. A later study suggested that modern American Blacks were improperly classified using Giles and Elliot's discriminant functions due to a secular trend toward higher cranial vaults and longer cranial bases in the African American sample (Ayers et al., 1990).

Johnson and coworkers (1989), using a small sample of Australoid, Caucasoid, Mongoloid, and Negroid skulls, devised a discriminant function for identifying race using cranial measurements and angles. Their work included mandibular and maxillary measurements. Palate length was amongst the most useful variables for race classification (Johnson et al., 1989). However, no single powerful method for assessing racial affinity has been developed for the dental arches.

What We Know of Racial and Sexual Variation in Dental Arch Breadth, Depth, and Shape

Many factors contribute to variation in dental arch shape and size including length of the jaws, length of the posterior tooth row, size of the teeth, distance between the glenoid fossa, and width of the symphyseal region (Aiello and Dean, 1990). Studies of racial and sexual variation in dental arch breadth suggest palate width is larger in males than females (Nummikoski et al., 1988; Goose, 1972). An interaction effect between sex and tooth position suggests that arch width increases more rapidly toward the posterior teeth in males than in females (Nummikoski et al., 1988). Developmentally, size and shape changes in both arcades were maximal between the ages of five to seven years and again from eleven to thirteen years in both males and females. These correspond to the ages of molar eruption (Lavelle et al., 1970). In later years, the palate widens in males between the ages of twelve and fifteen. In females, however, width does not exhibit significant change from the ages of twelve to twenty-six (DeKock, 1972). It is not completely understood why this differential rate occurs.

Significant sex differences in arch depth and breadth were demonstrated in Australian aborigine adolescents (Barrett and Brown, 1968). Adults and adolescents were similar in arch breadth, whereas adults had smaller arch depth dimensions. The differences were greater amongst males than females. These developmental changes may reflect the replacement of deciduous molars by smaller premolars, permanent canines undergoing anterior broadening and flattening after eruption, and reduced incisor procumbancy with age (Barrett and Brown, 1968). The latter supports greater reduction in males than females as males are less prognathic in the aborigine population (Barrett and Brown, 1968). The ratio of breadth to depth is larger in Australian aboriginal adult males than females, whereas the high correlation found between opposing maxillary and mandibular arches indicates the conformity of the maxilla and mandible (Barrett and Brown, 1968).

Arch breadth and tooth size vary dramatically between and within racial groups (Isaacson et. al, 1971; Goose, 1972; Fonseca and Klein, 1978; Nummikoski et al., 1988; Merz et. al, 1991). The need for normative values to assist clinical correction of malignments or perimortem tooth loss has generated a number of studies to quantify racial differences in arch dimensions and tooth size. Based on superior/inferior radiographs, Mexican Americans had the widest mandibular arches, followed by African Americans and European Americans (Nummikoski et al., 1988). Likewise, arch width measurement of dental models found Chinese palates much wider than British Whites (Goose, 1972). Mean maxillary and mandibular arch depth is larger in African Americans than European Americans (Merz et al., 1991). It was hypothesized that these differences were due to more labial inclination of the anterior teeth or a more distal placement of the molar, however this was not explicitly tested (Merz et al., 1991).

European Americans with a large mandibular plane to sella-nasion (MP-SN) angle have smaller arch width and increased dental crowding (Isaacson et. al, 1971; Merz et. al, 1991), whereas, a small angle is associated with larger arch width and increased overbite. African Americans have larger MP angles which should mean smaller arches and more crowding. However, African Americans show no significant increase in crowding (Merz et. al, 1991).

Measurement of maxillary and mandibular arches in four racial populations found significant variation in the White arch (Lavelle, 1977). The maximum discrimination between racial groups was found in Australoids and Negroids and the least in Whites and Asians. The mandible alone showed the greatest differences between Mongoloids and Caucasoids of both sexes (Lavelle, 1977).

Despite ample evidence of racial variation in arcade measurements, no study assessing the use of this variation in assigning racial affinity has been made. In addition to studies of metric differences amongst groups, variation in maxillary arcade shape has been observed by many (Kerley, 1973; Gill and Chapman, 1991; Gill, 1995; Rhine, 1990; Krogman, 1949). The European American palate has been described as parabolic or wedge-shaped with the teeth in an inverted "V". The African American palate has been described as hyperbolic or rectangular with parallel rows of teeth, and the Asian palate as elliptic or horse shoe shaped (Krogman, 1949; Gill and Chapman, n.d.; Gill, 1995; Kerley, 1973).

The only attempt to identify frequencies of specific palate shapes in different populations compared White, Black, Amerindian, and Polynesian skulls (Gill and Chapman, n.d.; Gill, 1995). Significant shape variation existed between males and females in all populations. The female samples were too small to analyze between group differences. However, males demonstrated racial difference in palate shape (Gill and Chapman, n.d.). The overall trend was for parabolic palate in Whites, hyperbolic palate in Blacks, and elliptic palate in American Indians (Gill and Chapman, n.d.; Gill, 1986; Gill, 1995). However, all groups displayed the parabolic shape in at least 50 percent of the individuals and three groups displayed the elliptic shape in at least 30 percent of the individuals (Gill and Chapman, n.d.; Gill, 1995). Further analysis of palate shape are necessary to elucidate differences between males and females and different racial affinity groups.

It has been suggested that arch shape is racially distinctive in the maxilla and not in the mandible (Krogman and Iscan, 1986). This is supported by studies that show significant racial width differences in the palate and not in the mandibular arch (Nummikoski et al., 1988) and less decrease in arch width in the mandible than the maxilla with a high MP-SN angle (see below) (Isaacson et al., 1971). However, similar differences in arch widths of the palate and mandible have been demonstrated in other studies (Merz et al., 1991). The full relationship between upper and lower arcade shape has not been explored.

In summary, racial variation in maxillary and mandibular arcade measurements has been demonstrated. Metric techniques that utilize differences amongst racial groups to determine the race of an unidentified skull have been published. The "v", hyperbolic, and elliptic shape of the palatal arcade has been studied nonmetrically for trends amongst races. These studies fail to evaluate metrically the maxillary and mandibular arcade shapes amongst large, racially distinct populations. Therefore I will quantify and statistically evaluate differences in maxillary and mandibular inter-tooth distances amongst African American, European American, and Asian samples.

CHAPTER 2

A HISTORY OF THE TERM "RACE" AND ITS SIGNIFICANCE IN MODERN ANTHROPOLOGICAL APPLICATION

Introduction

The identification techniques outlined in Chapter One exploit the morphological variation manifested in humans. These differences are used by anthropologists to subdivide the species *Homo sapiens* into races. Traditionally, biological races are based on geographic region because populations living more closely together tend to have similar phenotypic expressions and share more in common physically and genetically with their nearest neighbors. Races have been defined as populations that share a common gene pool within the group, and share fewer genes with other groups (Dobzhansky, 1971). The boundaries that separate one race from another are described by the biologist defining the race (Garn and Coon, 1955).

This traditional, populationist concept of race, however, is difficult to define exactly. Sub-specific fractions are subject to gene flow between declared races (Dobzhansky, 1971),discrete traits vary nonconcordantly (Lewontin, 1972), and clinal analysis reveals unique distribution of morphological traits on an individual level (Littlefield et al., 1982). Time and thus, evolution, directed by selective forces, causes populational variation to fluctuate. It is therefore difficult, yet not impossible, to draw racial boundaries between populations when the net result of evolutionary forces is modeled as a graded continuum across the globe.

The complexity in the definition of race has generated debate on the usefulness of race as a concept to science in general and anthropology in particular (Montagu, 1942; Livingstone, 1964; Sauer, 1978; Littlefield et al., 1982; Goodman, 1994; Brace, 1995). Does the concept warrant validation by the scientific community and anthropologists in particular? This chapter will address the issue.

History of Racial Classification

Early civilizations separated by great distances did not interact with the frequency that is common today. The mystery surrounding populations that looked strikingly different or had customs unusual to one's own led to many myths and legends. The ancient Egyptians and Greeks classified themselves and other groups based largely on mythical beliefs regarding skin color and body type differences (Brues, 1977).

The first known use of the word "race" was by Tant in 1606 (Lieberman, 1968; Banton, 1987). Exploration and colonization made Europeans aware of the abundant and varied plants and animals worldwide. Non-European human populations, dissimilar phenotypically from Europeans, generated European notions of savagery and degeneration from an ideal form (Lieberman, 1968; Gould, 1994). Idealogy regarding variation was based strongly on religious dogma. It was hypothesized that God created all creatures in a hierarchical order that could not change. There was no concept of organic evolution. Products of creation were ranked; Christian Anglo Saxons were rated just below angels and preceded inferior beings, including non-Anglo human populations (Goodman, 1994). The superior and inferior differentiation of human groups was largely based on skin color (Lieberman, 1968).

The desire to classify God's grand design developed into the science of taxonomy. Carolus Linnaeus in his 1735 and 1758 editions of *Systema Naturae* classified over 300 species of plants and animals (Greene, 1954). Linnaeus' taxonomy separated plants from animals at the Kingdom level and divided these two main divisions further into phylum, class, order, genus and species. Species were further divided into races, reintroducing the Fifteenth Century idea (Lieberman, 1968). A four race system for humans reflected the prejudices of the time by assigning moral and emotional qualities to each race (Goodman, 1994; Gould, 1994).

Linnaeus' work was revised by Johann Friedreich Blumenbach in 1775 and 1795 to include five races (Gould, 1994). Blumenbach's racial categories were Caucasoid, Mongoloid, American, Ethiopian, and Malayan (Gould, 1994).

Other naturalists designed racial categories and the number of races varied with the investigator from as few as four to many more (Nawrocki, 1993).

Differences between races were explained by either monogenic or polygenic doctrine, both of which relied on a typological philosophy with each race represented by a "type" or perfect form (Nawrocki, 1993). Blumenbach, a monogenist, held the notion that there was a single creation of humans similar to the Garden of Eden story from the Bible. After creation, humans dispersed over the globe. Different climates required regional adaptations called "degenerations", meaning a change from the original form or type that was given at creation (Lieberman and Reynolds, 1978; Gould, 1994).

Conversely, polygenism held that each race was a separately created species (Kennedy, 1976). The original "pure" races interbred and modified the typological morphology (Jurmain and Nelson, 1994). Polygenists viewed many human phenotypic traits as stable or nonadaptive. Their research questions focused on nonadaptive traits to determine which race was biologically most superior (Erikson, 1974; Gould, 1981). With both monogenism and polygenism individuals that did not conform to the type were viewed as deviant, therefore the range of morphological variability within race was not considered (Haller, 1970; Nawrocki, 1993).

Large cranial capacity was widely believed to represent a hallmark of human evolution. Larger brain volume equated to higher intelligence, superior morality, and a higher position on the taxonomic ladder (Gould, 1981). Craniometrics were thus employed to study racial differences in cranial capacity and to prove that the European race was superior (Gould, 1981). Gould argues in *The Mismeasure of Man* that craniometry has been used to "measure (sic) intelligence as a single quantity" (Gould, 1981:pp. 20) and elicit the biologically determined distinctions between races, classes, and sexes.

The polygenic-monogenic debate helped support and develop racist ideology (Lieberman, 1968). After the publication of Darwin's theories on natural selection races were seen as historical units that might evolve into new species. This changed somewhat with the rediscovery of genetics. After the early Twentieth Century, gene frequencies were studied to determine the evolutionary relationship between races (Banton, 1987). Other researchers, however, continued to define race taxonomically by distinguishing between geographical and microgeographical races (Garn and Coon, 1955).

Critique of racial typology was rigorously demonstrated by Franz Boas in the late 19th Century (Boas, 1899). Boas proved that traits used to classify races were mutable across generational lines. He found that the cephalic index, a ratio of cranial breadth to cranial length which was widely used to describe races, was highly discordant between immigrants and their children born in the United States and hypothesized that this was due to environmental factors such as better nutritional status (Boas, 1899). In some cases, the children would have been classified as a different race than their parents if craniometric data were used as a determinant (Gould, 1981). Boas' work raised questions regarding the definition of race.

Over the next three decades a paradigm shift placed morphological variation and its relationship to environmental adaptation, gene flow, and cultural selection at the forefront for research (Nawrocki, 1993). Race, and the search for race-specific nonadaptive traits, was perceived as an inadequate conceptual tool for addressing genotypic differences (Baker, 1971). The search for "pure" races was abandoned as well as the idea that all populational differences could be accommodated by racial classification (Bergman et al., 1961).

Ashley Montagu, an outspoken opponent of the term race and the implications that the concept of race had on scientific research and public perception, presented his theories in a paper before the American Association of Physical Anthropologists in 1941 (Montagu, 1964a). He conceded that populations differ in gene frequency; however, division into races promoted *a priori* classification and obscured data regarding variability (Montagu, 1964b).

Montagu's main objection to the term "race" for humans was its "long and tortured history" (Montagu, 1964b: pp. 84).

Racial typology and classification of human populations was rejected by many who instead focused on the distribution and evolutionary history of individual traits.(Nawrocki, 1993). Clinal analysis was used to establish the relationship between single traits and environmental conditions. Genotypical, physiological and cultural differences were studied from an evolutionary-adaptational perspective (Baker, 1971). Broad racial groupings were viewed as ill-suited for skeletal, dental, and sexual variation studies (Hiernaux, 1971).

Although it was agreed that gene frequencies differed between populations, multivariate clinal analysis revealed that different genes do not covary in their frequencies in correlation with other genes (Baker, 1967; Dobzhansky, 1971; Lewontin, 1972). Populations of humans separated by reproductive barriers and or exhibiting concordant traits were not shown to exist (Littlefield et al., 1982). Evaluation of one trait may generate a smooth division between groups, but addition of others gave different results (Livingstone, 1964).

Aside from scientific accuracy, a concern has been voiced regarding the social consequences and justification for racism that is fostered by continued use of the word "race" and the concepts behind the word (Littlefield et al., 1982; Goodman, 1994; Brace, 1995; Goodman and Armelagos, 1996). Race connotes difference that is interpreted as physical and, by some, moral. Certainly the history of racial classification is fraught with misuse and defense of racist attitudes and practices. Goodman and Armelagos (1996) hope anthropologists will lead the United States in an effort to eliminate race identification in research, demographic identification, and in turn, societal point of view for the purpose of combating a concept whose scientific validity is questionable.

Goodman appeals for the "critical analysis of the idea of race and how one's relationship with the idea further influences the choice of research questions and the results of one's research" (pp. 1, 1994). He contends that race, historically a social construct to explain human variability, has become a reality due to its reification by constant use and political usefulness (1994).

At the heart of Goodman's argument is the complexity involved in a definition of race. Definitions vary from geographic origin, to clusters of traits, to social categories (Brace, 1982; Goodman, 1994). For instance, Hispanic is a vague "social race" term that has replaced the unpopular term mestizo and indicates various combinations of European, Caribbean and Amerindian stocks (Rhine, 1990).

A compromise of sorts between those who wish to abolish racial terminology and racial categorization in research and those who believe explicitly in human classification into races has been proposed (Brace, 1995). Although the argument against the biological reality of race still exists, an acknowledgment that skeletal analysis allows an accurate estimation of geographical origin, especially of those with African, eastern Asian, and European roots has been added (Brace, 1995). Brace argues that "races" are not the result of differing selective forces. His evidence is the lack of congruence between typical morphological traits such as skin color and blood group with racial divisions. Skin color, a product of selective pressures varies with latitude and not longitude, therefore, it is useless in identifying regional biology. The same can be said for certain blood features such as Hemoglobin S that is evolutionarily linked with prevalence of falciparum malaria. Although the anopheles mosquito that carries this disease requires a hot and humid climate, Hemoglobin S is linked with the disease and not the geographic region.

Brace further states that the identification of race is associated with "political correctness". He claims the concept of race to be an American perpetuated concept that is a result of the blending of regionally distinct peoples in the New World, namely, Native Americans, Europeans, and West Africans (Brace, 1995). There is a general inability to distinguish race among the living. In the United States, statistics are kept based on social categories including race. Race is usually determined by the ancestry of the parents and the morphological characteristics of the individuals (Brace, 1995).

Race and the Forensic Anthropologist

Biologically, race is the subspecific division of a species based on morphological variation. Human populations tend to breed within their own population or with adjacent populations. This was especially true before world travel was so accessible, but it is largely true today (Howells, 1971). Populations have become further differentiated over time because of the forces of evolution, genetic drift, migration, mutation, but mostly natural selection and adaptation (Howells, 1971). Thus gene pools of different populations have unique gene frequencies and phenotypes.

An animal's worldwide distribution will effect the genetic and phenotypic differences between populations. If distribution is in one dimension as over a coastline, the populations differ by small amounts. If the distribution is two-dimensionsional, the differentiation becomes more complex. Geographical barriers or climactic shifts can lead to greater differences. In some cases the morphological differences can be clearly related to environmental function. In others the differences can only be used as a measure of biological distance (Howells, 1971)

Races are not distinct, discrete units. In fact, variation within each population can be enormous. Within group variation is not a function of size or isolation (Howells, 1971). In North America, populations from historically different geographical areas, Europeans, West

Africans, Native Americans, present a breeding population. Thus, the precision with which race can be applied to humans has limits. Nonetheless, variation amongst populations is present.

Nawrocki (1993) states that although "races do not exist as "pure" and discrete entities...certainly nonrandom clusters of heritable traits differentially exist in natural populations of humans and other organisms" (pp. 222). He argues that the split over race in anthropology is not over the biological data but is in the "philosophical approach to classification" (pp. 223).

In the Eighteenth Century, Blumenbach noted that his racial categories were more of a convenience than they were a category with overt biological meaning (Montagu, 1964a). There were not clear limits between different racial groups, instead there was a gradual continuation caused by a single region creation and then a spread over the globe (Gould, 1994).

The works of many early anatomists, physical anthropologists, and osteometrists have been cast aside as invalid because of the emphasis on racial differences. In many instances, the research was used to justify the inequality among human groups. However, the research has proved valuable in documenting human variation. Many physical anthropologists study the range of variation that exists on earth today and in the past. Frequencies of skeletal characteristcs within and amongst certain groups are established and unknown material is classified with a certain degree of accuracy based on skeletal characteristics.

When the "group" is "race" the subspecific demarcation can become complicated. Most forensic identification techniques are based on frequency studies of large populations of known race, age, and sex. Cultural standards influence the definition of race (Lieberman, 1996). The definition of race in the Terry and Hamman-Todd collections was based on phenotypic characteristics of each individual. "Negroes" in this collection were identified as such even if they exhibited many European American or American Indican characteristics. The cultural standard was to identify individuals as Negroid if any African American characteristics were present (Giles and Elliot, 1962).

Forensic anthropologists and perhaps other anthropologists see value in the concept of race identification (Sauer, 1988; Sauer, 1992; Kennedy, 1995; Brace 1995). Those working to identify an unknown skeleton or body realize the utility of any and all information. The National Computing Information Center (NCIC), the computer registry for missing persons, uses race as a demographic category. The race of a missing person or an unidentified body is documented as well as other clues to identity such as sex, age, stature, dental restorations, scars, tatoos, and information that makes an individual unique. This categorization is a reported sociological race based on genetic ancestry. Although population genetics certainly has it's place, specific population categories for the entire world are too broad in the applied forensic situation. The designation of much broader continental categories is very helpful as these are the categories generally applied in American culture and thus in the missing person files.

Brace concedes that the identification of race is a necessary component of our "prevailing sociopolitical milieu" (1995:pp. 174). The race identification that forensic anthropologists accomplish is typological despite the discordant distribution of both phenotypic and genotypic characteristics. Racial groups are selected, studied for within and between group variation, and an unknown specimen is evaluated for it's fit into a racial group. The term ancestral origin accurately reflects what racial identification methods are detecting and is a good compromise for forensic anthropologists. The forensic anthropologist must interact with the medicolegal system in a straightforward manner and that necessitates an evaluation of the unknown individuals ancestral background. The negative connotation indicated by "race" is lessened when "ancestral origin" is used and the information surmised from careful skeletal analysis is retained.

CHAPTER 3
RESEARCH MATERIALS AND METHODS

Purpose

The goals of this research were as follows:

1. To supplement the craniometric data used for racial identification of skeletal remains with data specific to the jaws.
2. To determine if there is racial variation in maxillary and mandibular arcade shapes.
3. If such variation is present, to describe it mathematically in order to predict the race of an unidentified human skull, cranium, or mandible.
4. To determine secular trend changes in the maxillary and mandibular arcades from the late 18th and early 19th Centuries to the present.

Sample

Skull Sample

Because the methods and information generated are to be used to identify modern people the most contemporary skeletal populations available were studied. All of the skeletal samples were comprised of individuals who died between 1860 and the 1930s. Only individuals with a full set of teeth through the second molars, no antemortem tooth loss, and no gross abnormality of the dental structures resulting from ante- or postmortem fractures were included.

Three racial categories were used; African American, European American, and Asian. The African American and European American skeletons are from the Terry Collection at the National Museum of Natural History, Smithsonian Institution and the Hamann-Todd Collection at the Cleveland Museum of Natural History. These collections were amassed from medical school cadaver populations of African American and European American individuals in the early part of this century.

The Asian skeletons are from two samples housed at the Smithsonian Institution, those from Urga, Mongolia and Chinese individuals from Kodiak Island, Alaska. The skulls in the Mongolian collection were well preserved, but many had no single rooted anterior teeth and several lacked mandibles. The Mongolian individuals died between circa 1870 and 1912 (Hrdlicka, 1912; Dave Hunt, personal communication). The Chinese males from Kodiak Island, Alaska most likely died between 1860 and 1910 (Hrdlicka, 1944; Dave Hunt, personal communication).

Dental Model Sample

In order to test for secular change in the jaws from the early part of this century to current American populations the data were compared to dental models of individuals from the last two decades. The models were cast from patients of the University of Florida Orthodontic Clinic who were treated from the mid 1970's to the early 1990's. Cranial measurements and some dental measurements were not possible on the models, thus the number of variables was reduced.

Skull Sample Size

Although the goal was 100 males and 100 females per racial group, sample sizes were often smaller due to availability. The African American sample had a total sample size of 201 individuals, 59 females and 77 males from the Terry collection and 42 females and 22 males from the Hammann-Todd collection. The European American sample had a total sample size of 186 individuals, 19 females and 24 males from the Terry collection and 67 females and 76 males from the Hammann-Todd collection. The Asian sample had a total sample size of 173 individuals, 46 males from the Kodiak Island collection, 55 females and 72 males from the Urga, Mongolia collection. Seventy-three Asian crania (31 female and 42 male) had no associated mandible.

Dental Model Sample Size

The sole dental specialty that retains models for any length of time is orthodontics. This necessarily limited the available models to those seeking orthodontic evaluation and thus a non-random sample of dental patients represented mostly by European and African Americans. Asian individuals were underrepresented (N=6 females and N=2 males) in the dental model data set and were not evaluated.

The sample included 27 African American females, 21 African American males, 103 European American females and 100 European American males.

Preliminary Study

A pilot study established which of 78 variables most readily distinguished between racial groups in a sample of 131 individuals (22 African American males and 14 females, 13 European American males and 15 females, 44 Asian males and 23 females) from the Terry, Hammann-Todd, Kodiak Island, and Mongolian collections.

Description of Variables

Discrete variables included sex, race, and age (if known). Continuous variables consisted of measurements describing the size and shape of the cranial vault, face, mandibular body and rami. These included many standard craniometric measurements (Figures 3-1, 3-2, and 3-3) (Martin, 1928; Stewart, 1952; Giles and Elliot, 1962; Giles,

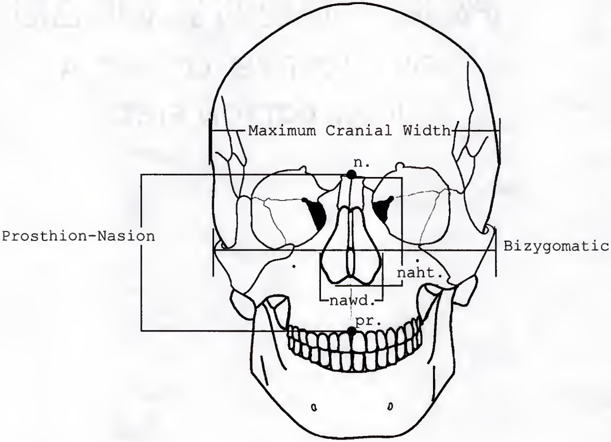

Figure 3-1 Measurements in the frontal view

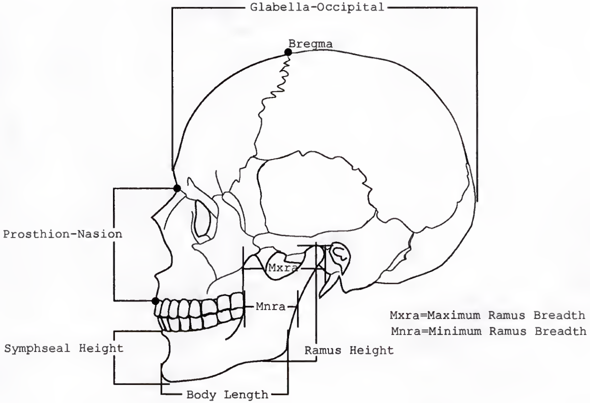

Figure 3-2 Lateral view Measurements

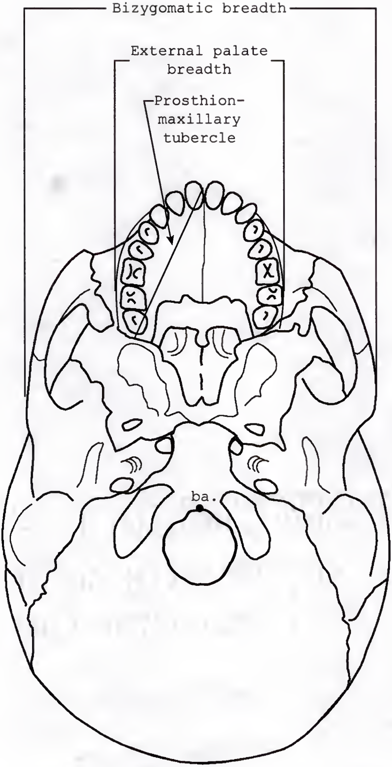

Figure 3-3 Basilar view measurements

1964; Howells, 1973). In addition, 40 arcade measurements (Figures 3-4 to 3-7) were created to describe the shape of the maxillary and mandibular arches. These measurements include minimum and maximum distances between bilateral teeth, maximum length from central incisor to second molar, and depth measurements from an imaginary plane transecting the arcade at the level of bilateral alveoli to a point just posterior to the central incisors.

Minimum distances (Figure 3-4) were measured between the same tooth on opposite sides of the jaw. The measurement was taken at the level of the alveolar border where the tooth initially erupts from the bone. This measurement was possible whether or not the tooth was present. Dial calipers were used.

Maximum distances (Figure 3-5) were taken at the most lateral point of the alveolus where the tooth initially erupted from the bone. This measurement could be taken with or without teeth in position. Sliding calipers were used for this measurement. As sliding calipers are accurate only to the millimeter, all measurements were limited to the nearest millimeter.

Depth measurements (Figures 3-6 and 3-7) were recorded from an imaginary coronally-oriented plane that bisected the arch. The plane was visualized using dental floss. The floss was placed distal to the bilateral teeth so that it stretched across the lingual space. The ends of the floss were weighted so the floss was taut across the space. The

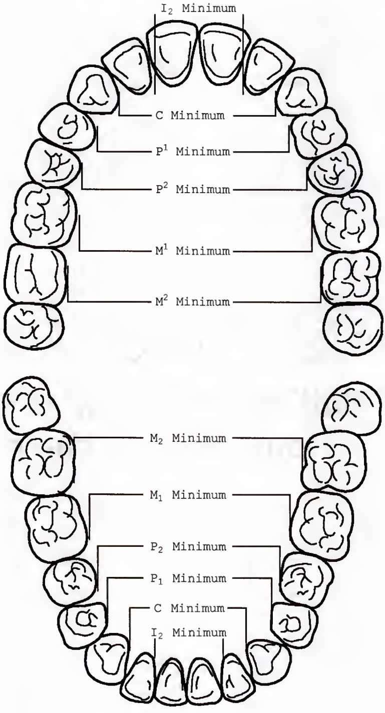

Figure 3-4 Minimum Distance Measurements

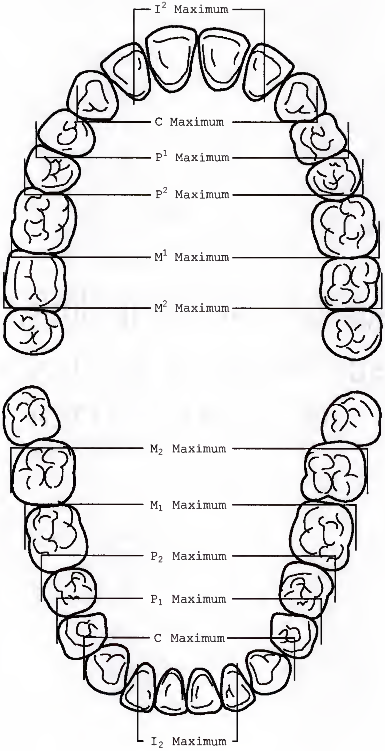

Figure 3-5 Maximum distance measurements

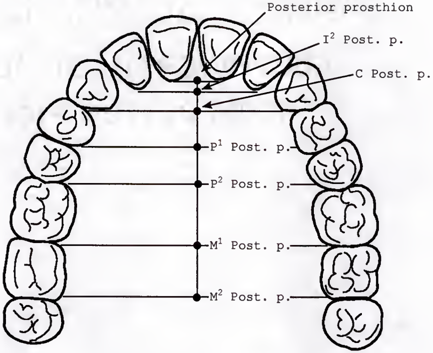

Figure 3-6 Depth measurements maxilla

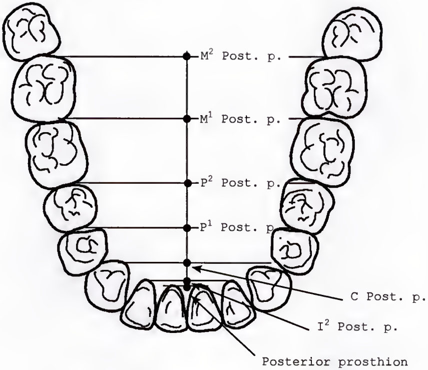

Figure 3-7 Mandibular depth measurements

measurement was recorded from this plane to a point named posterior prosthion. Posterior prosthion is defined as the point in the middle sagittal plane that intersects the line connecting the most distal points on the central incisor alveoli. The measurement was taken with dial calipers.

Cranial vault and mandibular body measurements (Figures 3-1 to 3-3) were taken using spreading calipers, sliding calipers, and a mandibuliometer (goniometer) following the definitions of Martin (1928), Hrdlicka (Stewart, 1952) and Giles and Elliot (1962).

Primary Study

The results of the premliminary study identified varibles most conducive to racial group discrimination. Variables that did not distinguish race well were not examined further. Tooth row length at both M2 and M3 levels

Table 3-1. Variables Measured in Preliminary Study (Abbreviations in Parentheses)

Cranial	Maxillary arcade	Mandibular corpus & rami	Mandibular arcade
Basion-Prosthion (bapr)	I2-I2 minimum & maximum distances (ui2mn & ui2mx)	Body Length (len)	I2-I2 minimum & maximum distances (li2mn & li2mx)
Basion-Nasion (bana)	C-C minimum & maximum distances (ucmn & ucmx)	Ramus Height (raht)	C-C minimum & maximum distances (lcmn & lcmx)
Basion-Bregma (babr)	P1-P1 minimum & maximum distances (up1mn & up1mx)	Gonial Angle (gona)	P1-P1 minimum & maximum distances (lp1mn & lp1mx)

Table 3-1--continued

Cranial	Maxillary arcade	Mandibular corpus & rami	Mandibular arcade
Glabella-Occipital (gloc)	P2-P2 minimum & maximum distances (up2mn & up2mx)	Minimum Ramus Width (mnra)	P2-P2 minimum & maximum distances (lp2mn & lp2mx)
Maximum Cranial Width (mxwd)	M1-M1 minimum & maximum distances (um1mn & um1mx)	Maximum Ramus Width (mxra)	M1-M1 minimum & maximum distances (lm1mn & lm1mx)
Bizygomatic (bizy)	M2-M2 minimum & maximum distances (um2mn & um2mx)	Bigonial Diameter (bidi)	M2-M2 minimum & maximum distances (lm2mn & lm2mx)
Prosthion-Nasion (prna)	M3-M3 minimum & maximum distances (um3mn & um2mx)	Thickness (thk)	M3-M3 minimum & maximum distances (lm3mn & lm2mx)
Nasal Height (naht)	Arcade depth at I2 level (ui2pp)	Symphyseal Height (syht)	Arcade depth at I2 level (li2pp)
Nasal Width (nawd)	Arcade depth at C level (ucpp)	Incisor-M2 (lm2tr)	Arcade depth at C level (lcpp)
External Palate Breadth (expa)	Arcade depth at P1 level (up1pp)	Incisor-M3 (lm3tr)	Arcade depth at P1 level (lp1pp)
Prosthion-Maxillary Tubercle (prmt)	Arcade depth at P2 level (up2pp)		Arcade depth at P2 level (lp2pp)
Incisor-2nd Molar (um2tr)	Arcade depth at M1 level (um1pp)		Arcade depth at M1 level (lm1pp)
Incisor-3rd Molar (um3tr)	Arcade depth at M2 level (um2pp)		Arcade depth at M2 level (lm2pp)

in upper and lower jaws (um2tr, um3tr, lm2tr, lm3tr) were eliminated due to small representation of the posterior molars. Table 3-2 lists the variables used in the final analysis.

Table 3-2. Variables measured in the primary study and their abbreviations

Abbreviation	
bapr	basion to prosthion
gloc	glabella to occipital
mxwi	maximum cranial width
bizy	bizygomatic breadth
naht	nasal height
nawd	nasal width
expal	external palate breadth
prmt	prosthion to maxillary tubercle
ucmn	minimum distance between upper canines
up1mn	minimum distance between upper first premolars
up2mn	minimum distance between upper second premolars
um1mn	minimum distance between upper first molars
up1mx	maximum distance between upper first premolars
up2mx	maximum distance between upper second premolars
um1mx	maximum distance between first molars
um2mx	maximum distance between upper second molars
len	length of the body of the mandible
mnra	minimum distance across the mandibular ramus
mxra	maximum distance across the mandibular ramus
thk	mandibular corpus width at the first molar
syht	symphyseal height of the mandible
lcmn	minimum distance between lower canines
li2mx	maximum distance between lower lateral incisors
lcmx	maximum distance between lower canines
lp1mx	maximum distance between lower first premolars
lp2mx	maximum distance between lower second premolars
lm1mx	maximum distance between lower first molars
lm2mx	maximum distance between lower second molars

Statistical Methods

Data were analyzed using the Statistica/Mac package (Statsoft,1991) and the SAS system (SAS Institute Inc., 1990).

ANOVA

One-way analysis of variance (ANOVA) models compare group mean values one variable at a time. ANOVA divides the variance into that due to the classification variable (between group) and the variation due to random error (within group) (SAS Institute Inc., 1990; Statsoft, 1991). The variation is computed using the sum of squares of deviations from the mean compared to the expected values under the null hypothesis. The null hypothesis in this case is that there are no mean differences between groups. The F value is the observed mean square divided by the expected mean square. Large F values indicate rejection of the null hypothesis. The probability of getting a large F value with a true null hypothesis is represented by the p-value (SAS Institute Inc., 1990). A p-value of 0.05 indicates error in rejecting the null hypothesis 5 percent of the time.

The one-way ANOVA results indicate whether or not there is a group mean difference. They do not, however, indicate which groups have significantly different means. To test individual group means against one another the Spjotvoll and Stoline Honest Significant Difference test, a generalization of Tukey's test for unequal sample sizes.(Statsoft, 1991) was used.

Two-way ANOVA allows consideration of more than one independent variable. Race and sex were used as independent variables and the data were analyzed in smaller groups.

MANOVA

Multivariate analysis of variance (MANOVA) can evaluate more than one dependent variable at a time. Multivariate tests explore error in variance between and within groups, however, the increased number of variables necessitates matrix algebra in the computations (Manley, 1986). The F statistic in MANOVA is a multivariate F named Wilkes' lambda.

In this work MANOVA was used to compare mean distance profiles amongst racial, sex, and era groups. Analyses were performed separately for upper jaw minimum and maximum, and lower jaw maximum distances. Wilkes Lambda test was used to test for the presence of significant interaction effects among relevant combinations of race, sex, era, and tooth position and to test for main effects associated with these factors.

Test for Normality and Sphericity

Profiles of the mean values of the inter-tooth distances were generated for comparisons of combination of race, era, sex. The Wilks-Shapiro test was used to test for the presence of significant non-normality of distance measurements within the various strata. Mauchly's criterion was used to test for a departure from sphericity of the within-subject distance error covariance matrix. A significant departure from sphericity indicated the presence of nonparallelism among individual subjects (distance profiles) within the various groups being analyzed.

Orthogonal Polynomial Contrast Tests

Tests were performed to detect the presence of linear and quadratic trends in the distance mean profiles (a line defined from anterior to posterior along the measured distances in upper and lower jaws). If such trends were identified the F test was used to determine whether the linear nature differed significantly between race groups.

Discriminant Analysis

Canonical discriminant analysis tested the ability of linear combinations of predictor variables to discriminate amongst the racial categories. An initial examination of the homogeneity of within-race covariance matrices was performed to determine if a pooled covariance matrix and linear discriminant function could be estimated and used to classify subjects by race or whether the within-race covariance marices and consequent quadratic discriminant function should be used to classify subjects. A cross-validation technique in which the discriminant function was estimated using all but one observation was then used to classify that one observation, with this process being repeated for every observation in a given set of subjects. Finally, a stepwise (forward stepping) canonical discrimnant analysis procedure was used to determine if the distances from a subset of positions would do a similar or perhaps better job of discriminating among racial categories than the original complete set. The subset of positions suggested by the procedure was then analyzed using both the parametric and non parametric approaches described above and subjected to cross-validation.

CHAPTER 4
RESULTS

Results of Preliminary Study

One hundred and thirty-one skulls from the Terry, Hammann-Todd, Mongolian, and Kodiak Island, Alaska samples were studied in a preliminary analysis to establish variables which distinguished between races. The composition of this group is presented in Table 4-1.

Table 4-1 Numbers of skulls used in preliminary study

	African American	European American	Asian
Female N	14	15	23
Male N	22	13	44
Total	36	28	67

One-way ANOVA was used to determine significant differences between group means for each variable. Measurements that showed significant mean difference between either all three pair-wise comparisons or two of three pairwise comparisons were retained for further exploration (Tables 4-2 and 4-3).

External palate breadth and lower tooth row length distinguished between all three racial groups. Many others expressed significant difference of means in two of three pairwise comparisons. African American cranial measurement means were significantly different from European American and Asian means in facial prognathism (basion-prosthion), length of the bony palate (prosthion-maxillary tubercle), and length of the tooth row. Asian means were significantly different from African Americans and European Americans in measurements describing cranial vault length and width (glabella-occipital and maximum cranial width) and nasal height. European American means were significantly different from African American and Asian in nasal width and bizygomatic breadth.

Table 4-2 Preliminary ANOVA results for the cranium and upper arcade

VAR	1	2	3	VAR	1	2	3	VAR	1	2	3
bapr	S	S	N	i2mn	N	N	N	i2pp	N	N	S
bana	N	S	N	cmn	S	N	S	cpp	N	N	N
bapr	S	N	N	p1mn	S	N	S	p1pp	N	N	N
gloc	N	S	S	p2mn	S	N	S	p2pp	N	N	N
mxwi	N	S	S	m1mn	S	N	S	m1pp	N	N	N
bizy	S	N	S	m2mn	N	N	N	m2pp	N	S	N
prna	N	N	S	m3mn	N	N	N	m3pp	N	S	N
naht	N	S	S	i2mx	N	N	N	Ant Shp	N	N	N
nawi	S	N	S	cmx	S	N	N	PostRow	N	S	S
expal	S	S	S	p1mx	S	N	S	M3 pos	N	N	N
prmt	S	S	N	p2mx	S	N	S	Overal	S	N	N
m3tr	S	S	N	m1mx	S	N	S				
				m2mx	S	S	S				
				m3mx	N	S	N				

KEY:VAR=Variable name;1=Black/White;2=Black/Asian;3=White/Asian
S=significant difference at 0.05; N=no significant difference
see Tables 3-1 and 3-2 for variable abbreviations

The intertooth distances across the arcade distinguished European Americans from the other two groups by the minimum bi-maxillary canine distance and minimum and maximum distances between first and second premolars and first molars.

In the mandibular measures, means for minimum and maximum breath of the rami and the height of the chin symphysis were significantly different in European Americans compared with the other groups. Mandibular corpus width was significantly thicker in Asian groups compared to European American and African American means. Ramus height, gonial angle, and bigonial diameter, and depth measurement of the arch showed no significant differences amongst groups.

Table 4-3 Preliminary ANOVA results for the mandible

VAR	1	2	3	VAR	1	2	3	VAR	1	2	3	VAR	1	2	3
manl	S	S	N	i2mn	N	N	N	i2mx	S	S	N	i2pp	N	N	N
ramht	N	N	N	cmn	S	S	N	cmx	S	S	N	cpp	N	N	N
gonang	N	N	N	p1mn	N	N	N	p1mx	S	S	N	p1pp	N	S	N
mnram	S	N	S	p2mn	N	N	N	p2mx	S	S	N	p2pp	N	S	N
mxram	S	N	S	m1mn	N	N	N	m1mx	S	S	N	m1pp	N	N	N
bigon	N	N	N	m2mn	N	N	N	m2mx	S	S	N	m2pp	N	N	N
thick	N	S	S	m3mn	N	N	N	m3mx	N	S	N				
symht	S	N	S												
m3tr	S	S	S												

KEY: VAR=Variable name; 1=Black/White; 2=Black/Asian; 3=White/Asian
S=significant difference at .05; N=no significant difference
see Tables 3-1 and 3-2 for variable abbreviations

Minimum mandibular bi-canine distance distinguished African Americans from the other two groups. No other minimum inter-tooth distance of the mandible was significantly different between groups. The maximum bi-mandibular distances of all but the third molars distinguished African Americans from the other groups.

MANOVA of Preliminary Study

The usefulness of grouped variables for predicting race was tested using MANOVA analysis. Results of Wilkes' lambda test are reported from variable groupings in Table 4-4. Significance was determined at the 0.05 level. It was not possible to group all of the variables at one time because the resulting matrix was near singular with a determinant nearly equal to zero and therefore impossible to invert. The data were, however, grouped into smaller units that described different areas of the vault and jaws.

Table 4-4 MANOVA results from preliminary variable groupings

Measurement Area	Wilkes lambda	p-value
Cranial vault	0.104061	0.0000
All upper teeth	0.164319	0.0042
Upper minimums	0.703582	ns
Upper maximums	0.606154	0.0461
Upper depth	0.734679	0.0143
Mandible body	0.161743	0.0000
All lower teeth	0.105591	0.0299
Lower minimums	0.704964	ns
Lower maximums	0.489655	0.0235
Lower depth	0.526136	0.0002

ns=nonsignificant, $p > 0.05$

Grouped cranial measurements, maxillary dental measurements, upper and lower maximum distances, upper and lower depth measurements, upper non-metric traits, body/rami measurements, and the lower dental measurements were significantly different between races (Table 4-4). Only the minimum distances for upper and lower jaws showed no significance when the traits were treated as a group.

Results of Primary Study

Descriptive Statistics for Skull Data

Descriptive statistics are reported in Tables 4-5, 4-6, and 4-7. Sample size varied greatly in the tooth measurements due to differential antemortem tooth loss rates (Table 4-6 and 4-7). African American samples were the largest and European American samples the smallest. European

Table 4-5 Descriptive statistics for skull variables; total sample size = 561

Variable	Race	Sample size (N)	Mean	Standard deviation
bapr	Black	192	100.4	6.74
	White	174	92.2	6.14
	Asian	165	95.8	6.10
gloc	Black	197	183.0	8.67
	White	182	177.9	9.03
	Asian	173	178.5	7.30
mxwi	Black	198	136.2	5.74
	White	182	141.2	7.21
	Asian	173	145.2	6.43
bizy	Black	200	128.2	6.80
	White	177	126.5	7.55
	Asian	146	145.2	6.64
naht	Black	201	50.0	3.51
	White	186	49.8	3.29
	Asian	173	53.5	3.38
nawd	Black	201	25.9	2.21
	White	184	23.0	2.28
	Asian	173	26.6	1.98
expal	Black	201	66.0	4.87
	White	182	60.2	4.51
	Asian	170	65.0	3.63
prmt	Black	194	57.1	3.63
	White	174	52.0	3.52
	Asian	162	52.9	3.55

American females had the greatest amount of antemortem tooth loss. In all three populations, the first molar was the most frequently missing tooth.

Table 4-6 Descriptive statistics for upper arcade variables; total sample size = 561

Variable	Race	Sample size (N)	Mean	Standard deviation
ucmn	Black	196	24.6	2.29
	White	172	22.8	4.50
	Asian	169	25.2	1.89
up1mn	Black	188	29.6	2.62
	White	159	28.0	2.77
	Asian	167	30.9	2.18
up2mn	Black	175	34.7	2.70
	White	141	33.0	2.92
	Asian	167	36.5	2.65
um1mn	Black	175	36.5	2.96
	White	127	34.7	3.27
	Asian	148	38.1	2.68
up1mx	Black	182	46.6	3.27
	White	153	42.8	3.11
	Asian	161	46.4	2.34
up2mx	Black	174	51.5	3.29
	White	137	48.1	3.24
	Asian	162	51.6	2.59
um1mx	Black	166	58.3	3.54
	White	123	55.3	3.53
	Asian	148	59.2	2.88
um2mx	Black	171	63.0	4.10
	White	133	58.7	3.75
	Asian	142	61.8	3.32

Table 4-7 Descriptive statistics for mandibular variables; total sample size = 488

Variable	Race	Sample size (N)	Mean	Standard deviation
len	Black	200	108.6	6.60
	White	184	104.8	6.45
	Asian	96	104.9	6.42
mnra	Black	199	33.2	3.90
	White	185	29.4	3.35
	Asian	99	34.5	3.35
mxra	Black	199	41.1	4.05
	White	184	38.6	3.88
	Asian	97	43.1	3.45
thk	Black	166	13.6	1.88
	White	150	12.7	1.61
	Asian	97	15.2	1.97
symht	Black	191	34.8	3.84
	White	169	31.3	3.07
	Asian	92	34.6	2.88
1cmn	Black	199	18.7	1.65
	White	184	17.4	1.73
	Asian	94	17.7	1.83
1i2mx	Black	195	18.7	1.91
	White	184	17.4	1.70
	Asian	92	17.6	1.97
1cmx	Black	198	31.7	2.05
	White	183	30.1	1.79
	Asian	94	30.0	1.92
1p1mx	Black	196	40.6	2.48
	White	172	33.4	2.18
	Asian	96	38.6	2.13
1p2mx	Black	183	47.2	2.66
	White	146	45.3	2.70
	Asian	95	45.5	2.82
1m1mx	Black	117	56.9	3.02
	White	85	55.1	3.10
	Asian	84	55.8	3.07
1m2mx	Black	150	62.6	3.30
	White	106	60.7	3.14
	Asian	81	60.9	3.18

Test for Normality

Many statistical tests are based on the assumption of a normal distribution of the variables. The Shapiro-Wilk test for normality was applied to the primary study variables. Results are reported in Table 4-8.

Table 4-8 Shapiro-Wilk test for normal distribution of variables

Variable	W:Normal	p value	Variable	W:Normal	p value
bapr	0.985908	0.5931	um1mx *	0.975922	0.0091
gloc	0.98245	0.1884	um2mx	0.979701	0.0809
mxwi *	0.976452	0.0032	len	0.980342	0.0923
bizy	0.980131	0.0647	mnra	0.980508	0.0988
naht	0.982578	0.1945	mxra	0.983294	0.3163
nawi *	0.970856	0.0001	thk *	0.947055	0.0001
expal *	0.979966	0.0487	symht *	0.977352	0.0201
prmt *	0.977727	0.0121	lcmn *	0.967909	0.0001
ucmn *	0.970408	0.0001	li2mx *	0.945173	0.0001
uplmn *	0.968879	0.0001	lcmx *	0.975051	0.0028
up2mn *	0.967126	0.0001	lplmx *	0.972534	0.0004
umlmn *	0.972869	0.0006	lp2mx	0.979293	0.0757
uplmx	0.98398	0.3800	lmlmx *	0.969611	0.0022
up2mx	0.980539	0.1056	lm2mx	0.978256	0.0858

* means significantly normal distribution at the 95 % confidence level

Eleven variables showed a distribution that differed significantly from normal (Table 4-8). These variables were basion-prosthion, glabella-occipital, bizygomatic breadth, nasal height, maximum distance between upper first premolars, between upper second premolars and between upper second molars, mandibular body length, minimum and maximum ramus width, and the maximum distance between the lower second molars.

It has been argued, however, that due to the robustness of the discriminant function test, the assumption of normality does not need to be rigidly adhered to (Klecka, 1979). This study, therefore, retains its statistical validity.

Descriptive Statistics for Model Data

Table 4-9 presents the descriptive statistics for the dental model data. Seventeen variables were evaluated for this sample. Cranial variables were not available, nor were mandibular body measurements possible on the dental models. One hundred European American males and females were evaluated, however, the numbers of African Americans and Asians was reduced. Twenty-seven African American female measurements and 21 male measurements were collected and analyzed. The number of Asians was too small to analyze.

ANOVA Results

1-way ANOVA Skull Data Set

Every variable showed significance using one-way ANOVA. The Spjotvoll and Stoline HSD test was used to determine whether this indicated that one group was different from the other two or all three group means varied significantly (Table 4-10).

The primary ANOVA results on the skull data set (Table 4-10) differed in several areas from the preliminary results most likely because of increased sample sizes. External palate breadth, which discriminated between all three races in the preliminary results, is no longer significantly

Table 4-9 Descriptive statistics for dental model data

Variable	Race/Sex	um2tr	ucmn	up1mn	up2mn	um1mn	up1mx	up2mx	um1mx	um2mx	lm2tr	lcmn	li2mx	lcmx	lp1mx	lp2mx	lm1mx	lm2mx
	AAF																	
Mean		56.8	26.5	28.4	33.4	34.7	47	51.8	58	63.4	54.1	20.6	22.4	33.1	41.7	47.3	55.8	61.4
SD		3.18	2.87	3.44	3.73	4.43	3.47	3.88	3.4	3.34	2.97	2.18	2.22	2.28	2.34	2.9	2.88	3.38
Minimum		52	22	23	24	21	42	41	51	56	49	17	19	30	37	41	49	53
Maximum		63	33	34	41	43	53	58	64	70	60	26	30	40	46	51	59	67
N	27	24	23	25	25	23	25	25	23	25	19	24	24	25	27	24	16	23
	EAF																	
Mean		52.9	23.3	25.4	29.8	31.7	42.8	46.9	53.7	58.3	49.5	18	20.1	30	37.2	43.7	52	57.5
SD		2.77	1.81	2.53	2.9	3.13	2.52	2.96	3.21	3.09	2.4	1.68	1.63	2.22	5.4	3.1	3.44	3.23
Minimum		47	19	17	23	23	35	40	46	51	43	13	12	19	4	33	45	51
Maximum		62	28	31	36	39	48	53	60	67	55	21	24	35	44	53	64	66
N	103	90	96	84	93	96	83	94	97	96	83	94	93	102	96	95	85	88
	AAM																	
Mean		59.8	26.7	30	34.7	35.8	48.9	53.9	60	65.2	55.5	20.3	22.4	33.5	42	48	56.8	62.6
SD		3.55	1.85	3.84	3.54	3.98	4.05	3.6	4.34	4.34	3.3	2.52	1.98	2.56	3.03	3.22	3.29	4.12
Minimum		53	22	22	26	28	40	45	52	55	45	14	18	28	33	41	51	55
Maximum		66	29	40	41	43	57	60	69	74	62	24	26	37	46	55	63	71
N	21	19	21	21	20	18	21	20	19	20	20	21	20	21	20	21	19	18
	EAM																	
Mean		54.6	23.9	26.7	31.1	36.6	44.8	49.1	55.7	60.9	51.1	18.8	20.5	31.2	39.9	45	53.9	59.9
SD		2.68	2.53	3.17	3.37	36.3	3.22	3.66	3.6	3.6	2.72	1.78	1.62	2.41	2.49	3.07	3.06	2.92
Minimum		48	18	16	23	23	34	40	47	53	45	15	16	20	30	37	48	53
Maximum		60	31	34	41	387	54	59	64	70	61	24	25	36	47	53	63	68
N	100	99	96	91	97	96	90	96	96	97	90	92	93	95	92	94	85	93

AAF = African American Female/ AAM = African American Male
EAF = European American Female/ EAM = European American Male

different between African Americans and Asians. Lower tooth row length was not evaluated in the primary study because of the small numbers of skulls with third molars.

Table 4-10 Results of Spjotvoll and Stoline honest significant difference test on all primary study skull variables

Variable	Black & White	Black & Asian	White & Asian	Variable	Black & White	Black & Asian	White & Asian
bapr	S	S	S	um1mx	S	N*	S
gloc	S	S	N	um2mx	S	S	S
mxwi	S	S	S	len	S	S	N
bizy	N*	S	S	mnra	S	S	S
naht	N	S	S	mxra	S	S	S
nawd	S	S	S	thk	S	S	S
expal	S	N	S	syht	S	N	S
prmt	S	S	N	lcmn	S	S	N
ucmn	S	S	S	li2mx	S	S	N
up1mn	S	S	S	lcmx	S	S	N
up2mn	S	S	S	lp1mx	S	S	N
um1mn	S	S	S	lp2mx	S	S	N
up1mx	S	N	S	lm1mx	S	N*	N
up2mx	S	N	S	lm2mx	S	S	N

S=statistically significant at p< 0 .05
N= not statistically significant (p> 0.05)
N* means p= 0.06

The variables that did show significant differences between all three group means based on Spjotvoll and Stoline HSD test are basion-prosthion, maximum width of the cranium, nasal width, minimum distance between the upper canines, minimum distance between the upper first premolars, minimum distance between the upper second premolars, minimum distance between the upper first molars, maximum distance between the upper second molars, minimum and maximum ramus height, and mandibular corpus width.

Other variables differentiated one racial group from the other two, but did not distinguish amongst all three. The African American sample differed from the others based on a larger glabella-occipital length, larger prosthion-maxillary tubercle length, larger mandibular body length, larger minimum distance between lower canines, larger maximum distance between lower lateral incisors, larger maximum distance between lower canines, larger maximum distance between lower first premolars, larger maximum distance between lower second premolars, and larger maximum distance between lower second molars.

The European American sample differed from the other two groups based on a smaller external palate breadth, smaller maximum distance between upper first premolars, smaller maximum distance between upper second premolars, and smaller symphysis height of the mandible. The Asian sample differed from the other two groups based on larger nasal height.

One-way ANOVA was also used to test for sexual dimorphism (Table 4-11). Only minimum distance between lower canines and maximum distance between lower lateral incisors *are not* sexually dimorphic. All other variables show significant differences between the sexes.

2-way ANOVA

The finding of sexual dimorphism necessitated evaluation of the interaction between sex and race. Two-way ANOVA allows appraisal of the combined effect of race and sex on

Table 4-11 ANOVA showing significant difference by sex on the primary skull variables with races combined

Cranial variables	p value	Upper arcade variables	p value
bapr *	0.0001	ucmn *	0.0020
gloc *	0.0001	up1mn *	0.0001
mxwi *	0.0001	up2mn *	0.0001
bizy *	0.0001	um1mn *	0.0004
naht *	0.0001	up1mx *	0.0001
nawi *	0.0001	up2mx *	0.0001
expal *	0.0001	um1mx *	0.0001
prmt *	0.0001	um2mx *	0.0001

Mandibular variables	p value	Lower arcade variables	p value
len *	0.0001	lcmn	0.1295
mnra *	0.0001	li2mx	0.9370
mxra *	0.0001	lcmx *	0.0001
thk *	0.0002	lp1mx *	0.0002
symht *	0.0001	lp2mx *	0.0082
		lm1mx *	0.0001
		lm2mx *	0.0001

* means significant difference between sexes at the 95 % confidence level

the measurement variables. A significant interaction means the relationship between one predictor variable, in this case sex or race, and the measurements is different for different occurences of the other predictor variable (Hatcher and Stepanski, 1994). The results of the test for interaction are shown in Table 4-12.

Fourteen variables, maximum width, bizygomatic breadth, prosthion-maxillary tubercle, minimum distances between upper second premolars, maximum distance between all paired bilateral teeth distal to the canine in the upper and lower jaws, mandibular length, and minimum distance between lower canines all presented interaction of race and sex.

Table 4-12 ANOVA showing the interaction effect between sex and race on the primary skull variables

Cranial variables	p value	Upper arcade variables	p value
bapr	0.2943	ucmn	0.1763
gloc	0.5078	uplmn	0.0643
mxwi *	0.0061	up2mn *	0.0050
bizy *	0.0006	umlmn	0.0762
naht	0.3138	uplmx *	0.0035
nawi	0.6695	up2mx *	0.0122
expal	0.2586	umlmx *	0.0120
prmt *	0.0256	um2mx *	0.0487

Mandibular variables	p-value	Lower arcade variables	p value
len *	0.0003	lcmn *	0.0480
mnra	0.7127	li2mx	0.4830
mxra	0.1401	lcmx	0.0628
thk	0.8511	lplmx *	0.0171
symht	0.4323	lp2mx *	0.0220
		lmlmx *	0.0010
		lm2mx *	0.0051

* means significant interaction between race and sex at the 95 % confidence level

The extent of this interaction necessitated separate evaluation for the sexes. The rest of the analysis was done with six groups African American male, African American female, European American male, European American female, Asian male, and Asian female (Tables 4-13 to 4-18).

Table 4-13 Descriptive statistics for Asian females

Variable	N	Mean	Std Dev	Minimum	Maximum
BAPR	52	92.67	4.71	82.00	108.00
GLOC	55	172.65	5.49	160.00	184.00
MXWI	55	143.29	5.28	133.00	155.00
NAHT	55	51.58	2.51	46.00	56.00
NAWI	55	25.80	1.67	22.00	30.00
EXPAL	55	63.20	2.77	56.00	71.00
PRMT	52	50.42	3.13	43.00	58.00
UCMN	55	25.15	1.68	21.00	28.00
UP1MN	54	30.85	1.78	27.00	36.00
UP2MN	53	36.64	2.18	32.00	41.00
UM1MN	49	38.06	2.57	33.00	46.00
UP1MX	52	45.96	2.26	41.00	52.00
UP2MX	52	51.25	2.50	44.00	57.00
UM1MX	48	58.50	2.61	53.00	65.00
UM2MX	48	60.85	2.69	53.00	66.00
LEN	23	104.04	6.46	88.00	115.00
MNRA	24	33.25	2.35	30.00	38.00
MXRA	23	41.83	2.82	37.00	47.00
THK	24	14.58	1.77	11.00	18.00
SYMHT	22	32.82	2.34	30.00	38.00
LCMN	23	18.43	2.04	14.00	23.00
LI2MX	22	17.77	1.63	15.00	20.00
LCMX	23	29.96	2.29	26.00	34.00
LP1MX	23	38.70	2.05	35.00	43.00
LP2MX	23	45.91	2.59	41.00	51.00
LM1MX	20	56.10	2.77	51.00	62.00
LM2MX	19	61.16	2.67	57.00	66.00

Table 4-14 Descriptive statistics for Asian males

Variable	N	Mean	Std Dev	Minimum	Maximum
BAPR	113	97.27	6.16	83.00	130.00
GLOC	118	181.20	6.44	165.00	195.00
MXWI	118	146.03	6.75	131.00	161.00
NAHT	118	54.43	3.36	45.00	64.00
NAWI	118	26.97	2.00	22.00	32.00
EXPAL	115	65.88	3.68	55.00	75.00
PRMT	110	54.06	3.12	47.00	61.00
UCMN	114	25.24	1.98	20.00	31.00
UP1MN	113	30.99	2.35	25.00	37.00
UP2MN	114	36.45	2.84	23.00	42.00
UM1MN	99	38.16	2.75	29.00	44.00
UP1MX	109	46.68	2.36	41.00	52.00
UP2MX	110	51.76	2.62	43.00	58.00
UM1MX	100	59.52	2.96	51.00	67.00
UM2MX	94	62.24	3.52	51.00	70.00
LEN	73	105.14	6.43	94.00	127.00
MNRA	75	34.95	3.53	26.00	43.00
MXRA	74	43.46	3.55	36.00	52.00
THK	73	15.47	2.01	12.00	22.00
SYMHT	70	35.16	2.82	30.00	42.00
LCMN	71	17.45	1.71	14.00	21.00
LI2MX	70	17.49	2.07	12.00	28.00
LCMX	71	29.99	1.81	25.00	34.00
LP1MX	73	38.58	2.17	33.00	46.00
LP2MX	72	45.40	2.89	37.00	52.00
LM1MX	64	55.77	3.17	49.00	63.00
LM2MX	62	60.87	3.33	51.00	66.00

Table 4-15 Descriptive statistics for African American females

Variable	N	Mean	Std Dev	Minimum	Maximum
BAPR	95	98.14	5.81	85.00	110.00
GLOC	100	178.55	6.70	164.00	196.00
MXWI	100	134.00	5.43	121.00	148.00
NAHT	101	48.75	3.20	38.00	59.00
NAWI	101	25.36	2.08	21.00	30.00
EXPAL	101	64.22	4.15	52.00	74.00
PRMT	95	56.23	3.26	49.00	64.00
UCMN	96	24.28	2.21	18.00	29.00
UP1MN	92	29.08	2.81	20.00	35.00
UP2MN	86	34.00	2.48	28.00	39.00
UM1MN	89	35.77	2.61	28.00	42.00
UP1MX	89	45.54	3.14	36.00	52.00
UP2MX	86	50.58	2.97	43.00	57.00
UM1MX	84	57.02	3.00	49.00	64.00
UM2MX	83	61.45	3.52	53.00	69.00
LEN	101	105.50	5.58	92.00	121.00
MNRA	100	32.16	3.65	23.00	43.00
MXRA	100	39.56	3.43	32.00	49.00
THK	76	13.25	1.71	10.00	18.00
SYMHT	97	33.19	3.37	23.00	40.00
LCMN	101	18.74	1.71	15.00	24.00
LI2MX	98	18.69	2.04	12.00	28.00
LCMX	101	31.15	2.06	27.00	40.00
LP1MX	101	40.06	2.44	31.00	47.00
LP2MX	89	46.53	2.49	42.00	54.00
LM1MX	50	55.36	2.68	51.00	61.00
LM2MX	73	61.15	2.97	56.00	69.00

Table 4-16 Descriptive statistics for African American males

Variable	N	Mean	Std Dev	Minimum	Maximum
BAPR	97	102.67	6.86	90.00	122.00
GLOC	97	187.60	8.08	170.00	210.00
MXWI	98	138.55	5.14	122.00	150.00
NAHT	100	51.36	3.33	42.00	58.00
NAWI	100	26.42	2.22	20.00	32.00
EXPAL	100	67.79	4.92	56.00	79.00
PRMT	99	57.94	3.79	50.00	67.00
UCMN	100	24.97	2.33	19.00	31.10
UP1MN	96	30.15	2.35	22.00	36.00
UP2MN	89	35.40	2.74	24.00	42.00
UM1MN	86	37.24	3.12	26.00	44.00
UP1MX	93	47.67	3.07	39.00	59.00
UP2MX	88	52.47	3.34	41.00	65.00
UM1MX	82	59.65	3.59	47.00	67.00
UM2MX	88	64.51	4.08	51.00	75.00
LEN	99	111.70	6.10	98.00	129.00
MNRA	99	34.17	3.89	26.00	45.00
MXRA	99	42.70	4.04	32.00	50.00
THK	90	13.96	1.96	11.00	20.00
SYMHT	94	36.52	3.56	25.00	45.00
LCMN	98	18.70	1.61	14.50	23.00
LI2MX	97	18.71	1.78	12.00	22.00
LCMX	97	32.20	1.90	28.00	36.00
LP1MX	95	41.19	2.39	33.00	47.00
LP2MX	94	47.77	2.69	41.00	56.00
LM1MX	67	58.10	2.72	52.00	65.00
LM2MX	77	63.95	3.02	56.00	71.00

Table 4-17 Descriptive statistics for European American females

Variable	N	Mean	Std Dev	Minimum	Maximum
BAPR	80	88.83	4.98	76.00	105.00
GLOC	86	172.44	7.06	156.00	186.00
MXWI	86	137.58	5.87	121.00	154.00
NAHT	87	47.92	2.65	39.00	55.00
NAWI	86	22.60	2.45	17.00	32.00
EXPAL	82	57.88	4.24	48.00	67.00
PRMT	77	50.42	3.22	44.00	57.00
UCMN	73	22.26	2.24	18.00	27.00
UP1MN	64	27.17	2.79	22.00	37.00
UP2MN	55	31.98	2.88	26.00	37.00
UM1MN	48	33.77	3.41	26.00	40.00
UP1MX	62	41.13	2.93	31.00	47.00
UP2MX	54	46.52	2.72	41.00	52.00
UM1MX	47	53.23	3.34	44.00	61.00
UM2MX	52	56.62	3.50	49.00	64.00
LEN	86	100.72	4.52	92.00	110.00
MNRA	86	28.09	3.56	20.00	37.00
MXRA	85	36.71	3.77	24.00	46.00
THK	56	12.36	1.43	9.00	16.00
SYMHT	71	29.76	2.33	25.00	36.00
LCMN	84	17.31	1.75	11.00	21.00
LI2MX	84	17.27	1.72	11.00	22.00
LCMX	83	29.45	1.63	23.00	33.00
LP1MX	74	37.43	2.07	32.00	44.00
LP2MX	54	44.28	2.57	39.00	54.00
LM1MX	27	53.11	2.87	49.00	61.00
LM2MX	39	59.41	2.80	53.00	65.00

Table 4-18 Descriptive statistics for European American males

Variable	N	Mean	Std Dev	Minimum	Maximum
BAPR	94	95.10	5.56	82.00	110.00
GLOC	96	182.72	7.76	161.00	209.00
MXWI	96	144.51	6.72	132.00	160.00
NAHT	99	51.45	2.89	45.00	59.00
NAWI	98	23.38	2.08	19.00	27.00
EXPAL	100	62.03	3.83	49.00	72.00
PRMT	97	53.34	3.20	45.00	61.00
UCMN	99	23.21	1.95	17.00	27.00
UP1MN	95	28.63	2.62	20.00	34.00
UP2MN	86	33.71	2.76	25.00	40.00
UM1MN	79	35.28	3.07	25.00	43.00
UP1MX	91	44.02	2.66	35.00	50.00
UP2MX	83	49.10	3.15	39.00	56.00
UM1MX	76	56.51	3.05	47.00	62.00
UM2MX	81	60.01	3.30	52.00	68.00
LEN	98	108.36	5.74	94.00	126.00
MNRA	99	30.52	2.72	24.00	38.00
MXRA	99	40.32	3.13	34.00	48.00
THK	94	12.95	1.68	9.00	19.00
SYMHT	98	32.46	3.06	25.00	39.00
LCMN	100	17.52	1.72	12.00	22.00
LI2MX	100	17.59	1.69	11.00	22.00
LCMX	100	30.70	1.72	27.00	34.00
LP1MX	98	39.12	1.99	33.00	44.00
LP2MX	92	45.87	2.61	40.00	52.00
LM1MX	58	56.02	2.76	51.00	63.00
LM2MX	67	61.42	3.12	52.00	70.00

ANOVA of Dental Model Data Set

The variables in the dental model set were also evaluated via ANOVA. The results are presented in Table 4-19.

Table 4-19 Results of ANOVA, sexual dimorphism and race/sex interaction on dental model variables

Variable	AFAM v. EUAM	MAL v. FEM	RACE*SEX
ucmn	S	N	N
up1mn	S	S	N
up2mn	S	S	N
um1mn	S	N	N
up1mx	S	S	N
up2mx	S	S	N
um1mx	S	S	N
um2mx	S	S	N
li2mx	S	S	N
lcmx	S	S	N
lp1mx	S	S	N
lp2mx	S	S	N
lm1mx	S	S	N
lm2mx	S	S	N

S=statistically significant at p< 0 .05
N= not statistically significant (p> 0.05)

All variables had means significantly different between African American and European American groups. With the exception of upper minimum canine and upper first molar distances, males and females differed significantly in group mean values. None of the variables measured on the dental model set had an interaction effect between race and sex.

Table 4-20 Results of Spotvoll and Stoline honest significant difference test on all dental model variables

VAR	BF WF	BF BM	BF WM	WF BM	WF WM	BM WM
ucmn	S	N	S	S	N	S
up1mn	S	N	N	S	N	S
up2mn	S	N	N	S	N	S
um1mn	N	N	N	N	N	N
up1mx	S	N	N	S	S	S
up2mx	S	N	N	S	S	S
um1mx	S	N	N	S	S	S
um2mx	S	N	N	S	S	S
lcmn	S	N	N	S	S	N
li2mx	S	N	S	S	N	S
lcmx	S	N	S	S	S	S
lp1mx	S	N	N	S	S	N
lp2mx	S	N	N	S	N*	S
lm1mx	S	N	N	S	S	N*
lm2mx	S	N	N	S	S	N

S=statistically significant at p< 0 .05
N= not statistically significant (p> 0.05)
N* means p= 0.06

Is Age a Confounding Factor?

The mean, median, and range of ages for the individuals in the European and African American samples were evaluated (Table 4-21). The ages of the Asian individuals were not available. In both skull and dental model samples the European American sample was statistically significantly older than the African American sample (p=0.0002 and p=0.036 respectively). However, when the data is examined, the mean age and the median ages are within the same decade. In the

Table 4-21 Descriptive statistics for the age variable in skull and dental model data samples

Data Set	Race/Sex	Mean	SD	Median	Range
Skull	AAF	36.3	13.2	34.5	18-83
	AAM	37.0	11.7	35.5	18-66
	EAF	40.4	12.7	38.0	18-80
	EAM	42.3	11.7	40.0	19-75
Model	AAF	24.6	7.2	23	18-37
	AAM	21.9	6.5	22	18-28
	EAF	26.8	6.8	25	18-57
	EAM	24.5	7.0	23	18-49

skull sample there is no sex effect (p=0.315) and in the model sample females are older than males (p=0.029). Again, although statistically females appear older, when the data is examined the average age of both sexes is in the third decade of life. A comparison of the skull sample to the dental model sample reveals an average age difference of 14 years. This is statistically significant (p=0.0001). The average age of the skull sample is 39.0 years and the model sample is 25.2 years. The individuals included in the study retained all dentition, so it is unlikely that there was an increase or decrease in arch width from age 25 to 39. Thus, age was not considered a confounding factor.

Discriminant Analysis

Skull Sample

The ability of the inter-tooth measurements in the skull sample to discriminate amongst racial groups was variable (Tables 4-22 to 4-24).

The Asian sample had the best classification rate for the maxillary measurements (Tables 4-22 and 4-23). The rate was 67% correctly classified using maxillary minimum measurements (Table 4-22). With these measurements the African and European American samples were correctly classified 50% and 43% of the time respectively (Table 4-22).

Table 4-22 Number of observations, percent classified into racial groups, and error rate for upper minimum distances

Race	African American	European American	Asian	Total
African American	82 50.31	30 18.4	51 31.29	163 100
European American	40 33.33	52 43.33	28 23.33	120 100
Asian	35 23.18	15 9.93	101 66.89	151 100
Total Percent	157 36.18	97 22.35	180 41.47	434 100
Error	0.4969	0.5667	0.3311	0.4585

Table 4-23 Number of observations, percent classified into racial groups, and error rate for upper maximum distances

Race	African American	European American	Asian	Total
African American	82 51.9	28 17.72	48 30.38	158 100
European American	21 17.07	70 56.91	32 26.02	123 100
Asian	26 18.06	17 11.81	101 70.14	144 100
Total Percent	129 30.35	115 27.06	181 42.59	425 100
Error	0.481	0.4309	0.2986	0.4047

The Asian sample was correctly classificed 70% of the time using the maxillary maximum distances. The African American sample was correctly classified 52% of the time and European Americans had a 57% correct classification rate (Table 4-23).

The African American sample was correctly classifed 76% of the time using the mandibular maximum distances. European American and Asian samples had much lower correct classification in the mandible at 39% and 33% respectively.

Table 4-24 Number of observations, percent classified into racial groups, and error rate for lower maximum distances

Race	African American	European American	Asian	Total
African American	110 76.39	19 13.19	15 10.42	144 100
European American	42 38.89	51 47.22	15 13.89	108 100
Asian	28 32.94	27 31.76	30 35.29	85 100
Total Percent	180 53.41	97 28.78	60 17.8	337 100
Error	0.2361	0.5278	0.6471	0.4332

Dental Model Sample

The correct classification of the European American dental model sample was 97% to 98% in the maxilla (Tables 4-25 and 4-26) and 96% in the mandible (Table 4-27). The

Table 4-25 Number of observations, percent classified into racial groups, and error rate for upper minimum distances in the dental model sample

Race	African American	European American	Total
African American	8 22.22	28 77.78	36 100
European American	4 2.61	149 97.39	153 100
Total Percent	12 6.35	177 93.65	189 100
Error	0.7778	0.0261	0.1693

Table 4-26 Number of observations, percent classified into racial groups, and error rate for upper maximum distances in the dental model sample

Race	African American	European American	Total
African American	11 28.95	27 71.05	38 100
European American	3 1.95	151 98.05	154 100
Total Percent	14 7.29	178 92.71	192 100
Error	0.7105	0.0195	0.1562

African American sample was correctly classified 21% to 29% in the maxilla (Tables 4-25 and 4-26) and 31% in the mandible (Table 4-27). The sample size was less than 40 individuals for the African American sample , however, the low results

Table 4-27 Number of observations, percent classified into racial groups, and error rate for lower maximum distances in the dental model sample

Race	African American	European American	Total
African American	9 31.03	20 68.97	29 100
European American	5 4.03	119 95.97	124 100
Total Percent	14 9.15	139 90.85	153 100
Error	0.6879	0.0403	0.1634

are suprising. The difference in correct classification between the skull data and the dental model data may be due to the nature of the dental model sample. Although every effort was made to screen the dental models and exclude abnormally developed jaws from the study sample, the models were pretreatment orthdontic models. Many of the individuals were health care workers or students selected by orthodontic students for evaluation and did not seek treatment on their own. However, the majority of the patient models evaluated were from individuals who were referred to the clinic by primary dentists. Because the dental model sample may be skewed by a high percentage of abnormal individuals, the discriminant function data can not be considered valid for comparison to unknown forensic cases.

Linear and Quadratic Trend Analysis of Skull Data

Maxillary minimum, maxillary maximum, and mandibular maximum distances were each tested to detect the presence of linear and quadratic trends in the shape from anterior tooth position to posterior tooth position. If such trends were exhibited, it was determined if they were of a similar nature for the racial samples or if they differed significantly between racial groups.

The results for the upper minimum distances found a significant interaction between race and tooth position with the differences among the races becoming greater moving from

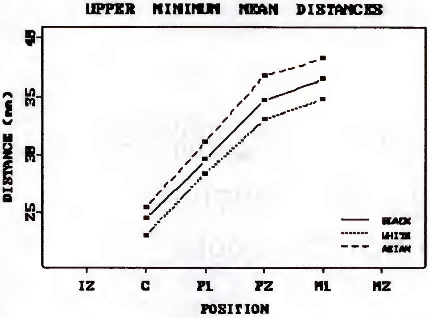

Figure 4-1 Interaction between race and tooth position for upper minimum inter-tooth distances in the skull data set

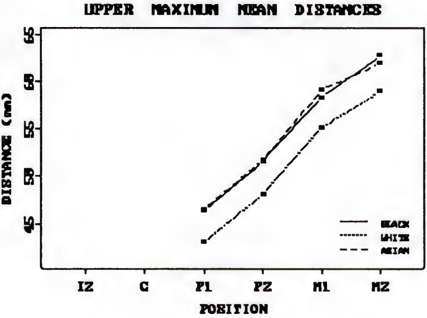

Figure 4-2 Interaction between race and tooth position for upper maximum inter-tooth distances in the skull data set

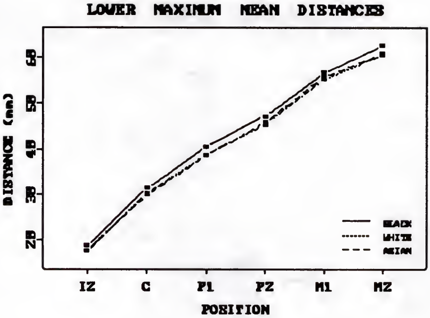

Figure 4-3 Interaction between race and tooth position for lower maximum inter-tooth distances in the skull data set

canine to first molar (Figure 4-1). The greatest difference was between African American and Asian groups.

Both quadratic and linear trends differed significantly between all three racial groups in upper minimum intertooth distances. Males and females differed significantly in the linear trend in the African American and European American groups, but not the Asian group. No significant sex effect was detected for the quadratic trend.

The results for the upper maximum inter-tooth distances found a significant interaction between both race and sex and tooth position with the differences between races and sexes becoming greater moving from first premolar to second molar (Figure 4-2). Quadratic and linear trends were significantly different between all three racial groups and between males and females for all three races in the upper maximum distance measurements.

The lower maximum distances also demonstrated significant interaction between race and tooth position and sex and tooth position. In both instances the differences increase moving from incisor to second molar. In both females and males, the interaction between race and tooth position among races showed the difference between African Americans and the other two groups increased from the incisor to the second molar (Figure 4-3). The lower maximum distances differed significantly between races in the quadratic trend, but not the linear trend.

Differences between Skull Sample and Dental Model Sample (Era Analysis)

The minimum and maximum arcade spanning distances were tested for difference between the early era skulls (Era 0) and the more modern dental models (Era 1). This analysis was limited to African and European American samples as Asian dental models were not available in great numbers (Table 4-28).

Table 4-28 Statistically significant differences in era for African and European American samples

Variable	African American	European American
ucmn	S	S
up1mn	N	S
up2mn	S	S
um1mn	N	S
up1mx	S	S
up2mx	N	N
um1mx	N	N
um2mx	S	S
li2mx	S	S
lcmx	S	N
lp1mx	S	N
lp2mx	N	S
lm1mx	N	S
lm2mx	N	S

S=statistically significant at p< 0 .05
N= not statistically significant (p> 0.05)

Two to four generations separate the skull and model samples. Era 0 inter-tooth distances are significantly different from Era 1 for both African and European American samples when the variables are analyzed univariately (Table

4-28). The Era 0 African American sample had significantly larger inter-tooth distances at bicanine. Era 1 was larger at the first premolar through second molar positions in the maxilla. In the mandible there was a decrease over time at the lateral incisor, canine, and first premolar positions and an increase at the second molar position. There was no significant change in the second premolar and first molar in the mandible.

Likewise, European American dental models (Era 1) had larger values for maxillary first premolar through second molar positions and smaller bicanine width. Era 0 had smaller mandibular second premolar through second molar distances in this sample. Thus, for both samples and in both jaws, the secular trend indicated smaller inter-tooth distances more anteriorly and increased posterior width with time. No interaction was found between era and sex for any variable in either sample.

Table 4-29 Multivariate analysis of position*era and position*sex in groupings of African and European American variables.

Group	Pos*Era	Pos*Sex
AAUpMn	S	S
AAUpMx	N	N
AALMx	S	S
EAUpMn	S	N
EAUpMx	S	N
EALMx	S	S

S=statistically significant at p< 0 .05
N= not statistically significant (p> 0.05)
AA=African American
EA=European American
Up=upper, L=lower, Mn=minimum, Mx=maximum
Pos=position

Multivariate analysis of the data grouped as maxillary minimum distances, maximum distances, and mandibular maximum distances found significant differences between Era 0 and Era 1 in all but African American maxillary maximum values (Table 4-29). It is not possible to say that Era 0 or Era 1 palates or mandibular arches were wider when these groupings were used because the trend was for an increase anteriorly and a decrease posteriorly.

CHAPTER 5
DISCUSSION AND CONCLUSIONS

Discussion

The primary data set provided information on race and sex differences in arch width. Asians had the widest inter-tooth maxillary distances. Asians were on average 5.3 mm wider, when the minimum distances were compared, than the next widest sample, the African Americans. African Americans averaged 6.9 mm wider than European Americans. This is similar to earlier research in which the maxillary arch of Mexican Americans was 0.2 mm wider than African Americans and European Americans were 0.8 to 1.2 mm narrower than African Americans (Numminkoski et al., 1988).

Asians also had the widest posterior maximum maxillary distances, whereas African Americans had the widest anterior maximum maxillary distances. African Americans were 0.2 mm and 1.2 mm wider respectively at the first premolar and second molar levels than Asians. Asians were 0.1 mm wider at the second premolar and 0.9 mm wider at the first molar than African Americans. European Americans were narrowest averaging 14.5 mm below African Americans and 14.1 mm less than Asians in maximum maxillary distances.

The mandibular arch of African Americans was the widest and the European American narrowest. These results contrast with a previous study that found African American mandibular arches significantly narrower than European American and Mexican American mandibular arches (Numminkoski et al., 1988). Different methodologies may be the source of dissimilarity between the studies.

The current study found Asian males to be 0.09 mm wider than females for upper cuspids, however, females were 0.98 mm wider than males for lower cuspids. African American and European American males were wider than females at the cuspid and molar levels in both upper and lower jaws with the upper differences larger than the lower jaw differences. In the molar areas Asian females were again wider than males in the mandible yet males were wider in the maxilla. Asian males and females did not differ in the mandible, however, African American and European American mandibles did show significant change with tooth position. All three race groups showed significant differences between males and females in tooth position in the maxilla. European Americans demonstrated the largest sex differences, followed by African Americans and then Asians. Previous studies found African American, Mexican, and European American males to be 0.6 mm wider in cuspid and premolar areas and 0.8 to 1.1 mm wider in the molar areas than females (Lavelle et al., 1970; Numminkoski et al., 1988).

When races were combined, males and females differed in palate width from anterior to posterior. Arch width increased more dramatically in males than females toward the posterior part of the arch. This result was also found in other work (Numminkoski et al., 1988).

Interestingly, one previous study found no interaction between race and sex (Numminkoski et al., 1988) while this study and others found a significant interaction effect (Giles and Elliot, 1962; Johnson et al., 1990).

ANOVA/MANOVA

This study confirmed the existence of race-specific patterns in the shape of the arcades. Measurements of the cranium, mandibular body and inter-tooth distances of the palatal and mandibular arcade showed group mean differences with ANOVA, MANOVA, and orthogonal polynomial contrast analysis.

Voluminous preliminary data was collected to explore the range of variation amongst racial groups and determine which variables would be the best predictors of race for unknown material. One-way ANOVA analysis was used as the deciding factor to continue with a variable or discontinue its study. Possibly 2-way ANOVA with sex and race as independent factors may have yielded variables less linked and more conducive to racial discrimination via discriminant analysis.

For example, the depth measurement of the arch in the preliminary results produced no significant group mean difference when analyzed one variable at a time. However, MANOVA analysis which considers all the depth measurements as a whole, showed significant results in the upper and lower jaws indicating a connection between depth measurement and race. Significant sex difference was found for arch depth in Australian aborigine adolescents (Barrett and Brown, 1968). Adults had smaller arch depth dimensions than adolescents, more so in males than females. With age there was a reduction in arch depth in relation to breadth. These changes in size and shape were more marked in males than females (Barrett and Brown, 1968). Although not followed up in the current research, further study of the depth measurement may yield information valuable to racial discrimination.

The reduction of variables based solely on 1-way ANOVA prevented the optimum data set in the primary analysis. The inter-tooth distances were reduced to four upper minimum, four upper maximum and six lower maximum. The data would have been easier to compare had the same teeth been used for each set.

Discriminant Analysis

The discriminate analysis results were mixed. The mandiular variables predicted African American ancestry with a 76% accuracy, however, European American mandibles were correctly classified less than 50% of the time and Asian mandibles were correctly classified even more infrequently. This was not suprising given that the 1-way ANOVA showed no significant difference between the European American and Asian samples when mandibular variables were analyzed separately. The Asian maxillary sample had the best correct classification attaining a 70% accuracy for the maximum distance variables. The African American sample had approximately a 50% accuracy rate in the maxilla and the European American ranged from 43% to 57%.

A discriminant function using the variables created in this study would, therefore, be valuable in predicting African American ancestry from the mandible and Asian ancestry in the maxilla. The near 50% accuracy rate for European American jaws makes this technique inadequate for assessing race in this group.

A possible explanation for the poorer results, despite significant difference in group means via MANOVA, is the lack of sphericity in the data sets (significant Mauchly's criterion). Although the racial group means often differed significantly from one another, individual subjects differed relatively inconsistently from their corresponding means.

This study supports previous discriminate analysis work of combined maxillary and mandibular dental arch dimensions. Similar measurements on smaller samples of different racial groups found the maximum discrimination in Australian

Aborigines and West Africans and the least in Caucasians and Asians (Lavelle, 1977). The mandible studied alone showed the greatest differences were between Asians and Caucasians of both sexes (Lavelle, 1977) and not African Americans as was demonstrated in this study.

When the entire cranium (Giles and Elliot, 1962) or skull (Johnson et al., 1988) was evaluated, 70 to 90 percent reliability was found. Johnson and coworkers (1989) found that Europeans (87 %) and Asians (97 %) were classified more reliably than Australian Aborigines (79 %) and West Africans (70 %). Giles and Elliot (1962) found European Americans, African American males, and Amerindian females were classified more reliably than Amerindian males and African American females.

Linear and Quadratic Trend Analysis of Skull Data

A significant difference between ancestral groups for linear or quadratic trends indicated that the positions of the teeth with regard to palate or mandibular arch width exhibited a pattern unique to a group. The graphs generated in the orthogonal polynomial contrast analysis (Figures 4-1 to 4-6) are a good representation of this pattern and mimic the width dimension as one moves from anterior to posterior in the dental arcade.

In the Asian group, the maxillary canines are spaced further apart than the other two groups. This difference in distance increases at the first premolar position and again at the second premolar position. The increase in palatal width is not as great between the first and second molars as is demonstrated by the other two groups. This type of pattern, a "horseshoe" or "U" shape, in the Asian maxillary arcade has been suggested to be a non-metric indicator of race (Kerley, 1973; Gill, 1986; Gill and Chapman, 1991).

Other non-metric patterns of maxillary arcade shape include a narrow "V" shape for European Americans and a hyperbola for African Americans (Kerley, 1973; Gill, 1986; Gill and Chapman, 1991). The inter-tooth distance graphs demonstrate that European American arcades are the narrowest and differ most from African Americans and Asians at the canine and second molar (Figures 4-4 to 4-6).

The African American maxillary premolar area is unique because the width between the teeth does not increase between the first and second premolars as much as in the other racial groups. This trend was also seen in the dental model data. It supports the nonmetric observation of a hyperbolic palate.

The African American palate is the widest of the three groups when maximum distances are compared, however, Asian groups are wider when minimum distances are used. This indicates larger tooth diameter at the alveolar border in African Americans. The maximum distances in the mandible are the largest in the African American sample and the smallest in the European American sample.

The mandible does not reflect shape differences similar to the maxilla. The three groups have significantly different quadratic trends in the mandible, however, the linear trends are not significantly different. This indicates that all three groups increase in width from lateral incisor to second molar, but differ in the curve shape from anterior to posterior tooth position. The European American and Asian pattern and widths are nearly identical, again confirming the ANOVA result of nonsignificant difference between these two groups in the mandibular measurements.

Era Analysis

A secular trend was discovered for the maxilla and mandible over the approximately two to four generations encompassed by this study. Several confounding factors complicate the interpretation of this trend . The modern sample was comprised of pre-treatment orthodontic dental models. Orthodontics is the one specialty in dentistry in which the models are retained for many years and in which a large number of dental models were readily available. The models were carefully screened and developmentally abnormal individuals were eliminated. Nonetheless, these were individuals who were seeking orthodontic evaluation. Many were evaluated at the clinic and advised that no treatment was necessary; however, many of the individuals used in this study did receive orthodontic treatment to correct malignments. Inclusion of orthodontically abnormal individuals aids in evaluating the full range of variation present in modern populations. However, the palatal arch tends to be bowed and the arcade crowded in these individuals. A measurement of the vertical depth of the palate may have aided in screening the models. Because the entire "modern" sample is comprised of dental model patients the results may be skewed.

Another confounding factor in the era analysis is comparing a Florida dental clinic population with cadaver populations from Northern states. Again, combining these regions of the United States and combining differing socio-economic levels aids in establishing the full range of variation that may present as a forensic case. However, in the era analysis in which the skull and dental model samples were compared, the variation between the samples may confound the interpretation of secular trend differences.

Nonetheless, the trend of increased anterior width and decreased posterior width in the dental arcades that was demonstrated in this study has been observed in previous work. A study of changes in bicanine and second molar inter-tooth distance through evolutionary time for Australopithicenes, *Homo erectus*, *Homo sapiens neandertalesis*, hunter gatherer populations, and very modern *Homo sapiens sapiens* found similar results. The rate of change (velocity) per 100,000 years was found to be 0.29 for the bicanine width and -0.4 for the second molar inter-tooth distance and the change of rate (acceleration) to be 1.89 and 1.15 respectively (Wolpoff, 1975). The most modern *Homo sapiens* bicanine and bimolar breadths all decreased by 10% from the hunter-gatherer populations.

Application of Results to Forensic Anthropology

As far back as Krogman (1949) the maxillary dental arcade shape has been referenced as a reliable indicator of racial affiliation. This study provides clarification through metric data about shape differences in the palatal and mandibular dental arcades amongst the three most commonly used racial groups. This study proves that ancestral origin differences in width between bilateral teeth do exist. Asian maxillae are widest, African American next widest, and European American narrowest. Discriminant functions describing the maxilla with the inter-tooth distances give 43% to 67% correct classification. This method is not accurate enough to be useful by itself in a forensic setting. However, the data supports the reported "V", "hyperbola", and "horseshoe" shaped maxillary arcades found in European American, African American, and Asian populations respectively. A combination of the observed shape (relative inter-tooth distances) and one or more measurements across the arcade compared with the average values for race/sex groups generated by this study does provide good estimation of ancestral origin.

A secular trend for change in inter-tooth width was revealed for African and European American samples. Anterior maxillary tooth position widths increased in both groups and posterior widths decreased in the European American mandible sample. These statistically significant differences are difficult to interpret because the early and modern samples are noncongruent. The modern sample was comprised of orthodontic patients who may not accurately reflect the full range of variation found in modern Americans. The suitability of the skeletal collections most commonly used in forensic research as indicators of the modern condition must still be evaluated.

The mandible differed from the maxilla in that shape differences between ancestral groups were not observed. The relative distances from lateral incisor to second molar were similar in all three groups thus no information useful to ancestral assessment was gained. Discriminant function results using inter-tooth distances in the mandible were good for distinguishing the African American samples (76% correct classification). This mathematical model applied to unknown mandibles would distinguish African American individuals.

Conclusions

1) Significant differences were found in measurements of width in the maxillary and mandibular arcades in Asian, African American, and European American groups. The Asian maxilla was widest, African American next widest, and European American the most narrow. The African American mandible was widest, Asian next widest, and European American most narrow.

2) The differences in width of the maxillary and mandibular arcades resulted in mixed accuracy rates.

Asians had the best result in the maxilla with a 67% to 70% correct classification rate. The Asian mandible, however, was correctly classified only 35% of the time.

The African American sample had about a 50% correct classification in the maxilla and a 76% correct classification in the mandible.

The European American sample had a 57% to 43% correct classification in the maxilla and a 47% correct classification in the mandible.

3) Linear and quadratic trend data supports previous notation of non-metric shape characteristics useful for distinguishing race group from the maxillary arcade. The pattern formed by relative distances between bilateral teeth in the Asian maxilla supports the observation that this group

has a "horseshoe" or "U" shaped arch. The pattern demonstrated by the European American data supports a narrow "V" shape to the maxillary arch.

4) African American and European American groups showed a similar trend for statistically significant larger width over time at the following tooth positions: maxillary canines, first premolars, and second molars; mandibular lateral incisors. A decrease in width was noted for the upper second premolar position in both groups. European American data reflected a decrease in width of the mandibular posterior teeth (second premolar, first molar, second molar).

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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December, 1996

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